MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

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MEETING OF 1933 JANUARY 12

Prof. F. J. M. Stratton, President, in the Chair.

The election by the Council of the following Fellows was duly confirmed :—

Herbert Moore Attwell, 14 Radnor Park Avenue, Folkestone ;
Leslie Francis Ball, "Auriga," 5 Craigweil Avenue, Didsbury, Manchester;
Harold Bewick, A.M.I.C.E., 45 Percy Park, Tynemouth, Northumberland;
William Moses Feldman, M.D., B.S., M.R.C.P., M.R.C.S., 851 Finchley Road, London, N.W. 11 ;
George Henry Gilbert, B.Sc., Launceston College, Cornwall ;
Haldan Keffer Hartline, M.D., Bloomsburg, Pa., U.S.A. ;
K. Mahmood Hussain, M.A., King Kothi, Hyderabad, Deccan, India ;
Reginald William John Payne, 64 Blackheath Road, Greenwich, London, S.E. 10 ;
Edwin Wilbur Rice, jun., General Electric Company, Schenectady, New York, U.S.A. ;
Walter Alexander Scott, B.Sc., 190 Rochester Way, Kidbrooke, London, S.E. 3 ; and
Lakshmanathirthakatte Sibaiya, M.Sc., A.Inst.P., Assistant Professor of Physics, Central College, Bangalore, S. India.

Eighty-three presents were announced as having been received since the last meeting, including :—

Córdoba Observatory, Resultados, vol. 30 (Astrographic Catalogue, zone $-28°$).
Princeton Observatory, "Atomic Lines in the Sun-spot Spectrum," by Charlotte E. Moore.

The President announced that the Gold Medal of the Society had been awarded to Dr. Harlow Shapley, Director of the Harvard College Observatory, for his Studies of the Structure and Dimensions of the Galactic System.

THE SPATIAL DISTRIBUTION OF THE EXTRA-GALACTIC NEBULÆ WITHIN A RADIUS OF 4000 KILOPARSECS.

J. H. Reynolds, M.Sc.

It is implicitly assumed in the theoretical work of De Sitter and others on the expanding universe that matter is distributed in such a way that there is no marked asymmetry in the extra-galactic nebulæ. It is not the purpose of this paper to try to determine whether the amount of asymmetry which undoubtedly exists within a limiting radius of 4000 kiloparsecs is sufficient to affect the theoretical conclusions or not. As we have now ample observational material to form some idea as to the spatial distribution within that limit, it is in any case of interest to record the available evidence. If statistical means of the angular dimensions of spirals, compared with the actual dimensions in parsecs of those systems which are near enough to give determinate distances, are taken, the limit of 4000 kiloparsecs is equivalent to a maximum diameter for this class of the order of 5′, which is therefore taken as the minimum limit.

It is necessary to separate the extra-galactic nebulæ into three classes, viz.: (1) the Irregular, (2) the Spirals, and (3) the Elliptical.

(1) The irregular are apparently few in number, and although they include two such important local systems as the Magellanic Clouds, they are not of importance as a class.

(2) The spirals of 5′ and upwards have been photographed and catalogued at several observatories, including the Helwân Observatory and those derived from the Franklin-Adams plates (*vide M.N.*, **81**, 598, 1921). It is unlikely that more than 10 per cent. are still unknown over the whole sky. This class yields the best evidence of distances yet available.

(3) The elliptical nebulæ are extremely numerous compared with the spirals, very often appearing on the same plates in considerable numbers. There is good evidence that they are intrinsically of very small diameter and mass compared with the spirals. Many of them appear as nebulous star discs of a few seconds diameter, and the great majority of the thousands of the new nebulæ discovered and catalogued are of this class. The largest in angular diameter (8′) is N.G.C. 205, one of the companions of the Andromeda Nebula. The other bright companion, N.G.C. 221, is only 2′·5 in diameter.

It is impossible to say what proportion of the elliptical nebulæ are probably situated within the radius of 4000 kiloparsecs. As the brightest of those in the groups in Perseus, Pegasus, Pisces and Cancer were found by Hubble to have large radial velocities, ranging from 3500 to 8000 km./sec.

(and *ex hypothesi* therefore to be regarded as very distant objects), the proportion is likely to be quite small.

The Comparative Dimensions of the Three Classes of Extra-galactic Nebulæ

In *Mt. Wilson Cont.*, No. 427, Hubble and Humason give estimates of the distances of various systems.

There are four criteria which can be used as guides in arriving at such estimates :—

1. The angular diameters.
2. The integrated magnitudes.
3. The observation of stars of various classes in the nearer systems.
4. The degree of spectrum shift corrected for the rotation of the Galaxy.

(1) is applicable to the three classes separately, and must be based on the average dimensions of each class. In the case of spirals, all angles of orientation should be considered, including the "edge-on" spirals.

(2) is subject to the same conditions, but it is complicated by a further necessary division of the spirals according to the degree of condensation into nodules, and star-like concentrations. This further division makes it less reliable in some respects than (1), as it is possible for a spiral to be of small integrated magnitude owing to a high degree of condensation, and yet of large angular diameter, including faint stars which can be used as direct gauges of distance. Such objects are relatively nearer than many uncondensed spirals with bright nuclei and therefore brighter integrated magnitudes. In the hands of Hubble this criterion, distributed over a large number of spiral and elliptical nebulæ, has yielded valuable results in connecting distance with spectrum shift. As the "edge-on" spirals have apparently been excluded by him in obtaining the mean integrated magnitudes of the spirals, owing to their small integrated magnitude compared with the diameters, angular diameters have been taken as the criterion in the present paper. A considerable proportion of the spirals of 5′ diameter and upwards are inclined at an angle of less than 30° to the normal.

(3) is much more reliable than either (1) or (2), but can only be applied to the nearer and condensed nebulæ where star discs can be photographed.

(4) Whatever may be the interpretation of the spectral shifts, there seems to be no doubt that there is a direct relationship between the amount of the shift and distance. This, therefore, may prove to give the best determination of all, as it must be independent of any other factor than the galactic rotation, which can be eliminated. It is equally applicable to any of the three classes of nebulæ.

The following table gives the dimensions in parsecs of some nebulæ of each class based on estimates of distance adopted by Hubble * from the photographic magnitudes of various types of stars in the systems. In the more distant objects the faint stars observed are assumed to be of the maximum intrinsic luminosity −6 mag. abs.

* *Comm. Nat. Acad. Sci.*, No. 105.

TABLE I

Irregular

System	Distance in Kiloparsecs	Angular Diam.	Approx. Diam. in Parsecs
Gt. Mag. Cloud	26	7°	3300
Sm. Mag. Cloud	29	3°·6	1800
N.G.C. 6822	192	20′ × 10′	1100
4449	630	3′·5 × 2′	700
4214	800	8′ × 4′	1800
		Mean	1700

Spirals

System	Distance in Kiloparsecs	Angular Diam.	Approx. Diam. in Parsecs
N.G.C. 598 (*M*33)	234	60′	4100
224 (*M*31)	245	130	9000
5457 (*M*101)	400	16	1900
5194 (*M*51)	450	12	1500
253	700	22	4500
2403	630	16	3000
3031 (*M*81)	800	16	3800
3627 (*M*66)	800	8	1900
4826 (*M*64)	800	8	1900
5236	800	10	2300
5055 (*M*63)	980	8	2200
7331	980	9·5	2700
4258	1250	20	7300
55	(700)*	25	(5000)
247	(700)*	20	(4000)
300	(700)*	20	(4000)

* Estimated from negatives at the Helwân Observatory.

Elliptical

System	Distance in Kiloparsecs	Integrated Magnitude	Angular Diam.	Approx. Diam. in Parsecs
N.G.C. 205	245	11	18′	500
221	245	9	2·5	160
3379	1300	10	2	750
4382	1200	10	4	1400
4472	1200	9·5	2	700
4486	1200	10	2	700

The distances of the elliptical nebulæ given above are subject to considerable uncertainty. The first two by reason of their proximity to the Andromeda Nebula, and their similar and unusual radial velocity may be regarded as being of the same order of distance with some certainty. Only in the case of N.G.C. 4486 are there any faint stars visible, the brightest being of magnitude 19·5. The distance given for this is the same as for spirals showing stars of the same magnitude. In the other cases the integrated

magnitudes and spectrum shift have been used as indications of distance. In any case it is evident that the elliptical nebulæ are generally of a much smaller order of magnitude than the spirals.

The most reliable determinations are N.G.C. 205, 221 and 4486. Hubble gives mean diameters in parsecs of 380, 620 and 1000, for elliptical nebulæ of ellipticities 0, 1/2 and 2/3 respectively (*Mt. Wilson Cont.*, No. 427).

If we imagine N.G.C. 221 to be removed to a distance of 4000 parsecs

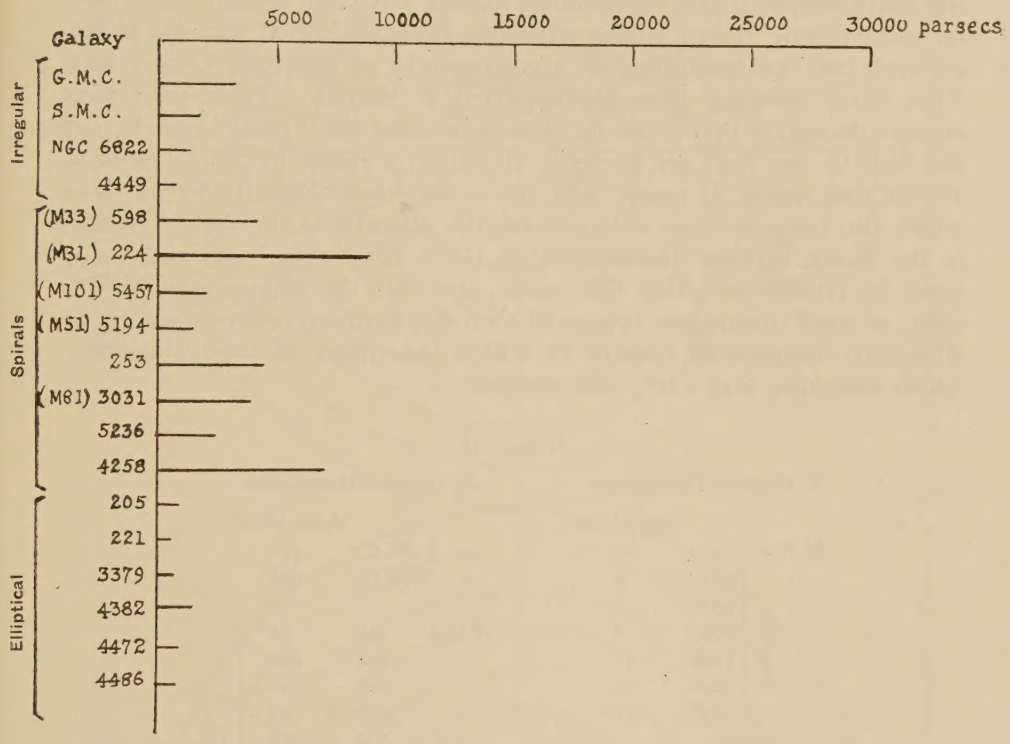


FIG. 1.—*Comparative Dimensions of the Galaxy and Extra-galactic Nebulæ at Hubble's estimated distances.*

it would appear photographically as a hazy star disc 7″ diameter of the 16th integrated magnitude; in fact, a very similar description to the hundreds of new nebulæ recorded as "faint, small, round," or "elongated."

Comparative Dimensions of the Extra-galactic Nebulæ and the Galaxy

It will be seen from the table that the majority of spirals must be of much smaller dimensions than the Galactic System, for which 30,000 parsecs would be taken as a minimum, even after allowing for a certain small absorption of light in the galactic plane. Most of the spirals range between 2000 and 5000 parsecs, and it is evident from the photographs that there must be a considerable difference in mass, even in those of the same diameter.

Fig. 1 gives the estimated diameters of examples of the three classes of nebulæ, compared with the Galaxy.

The Spiral and Irregular Nebulæ within a radius of 1000 *Kiloparsecs*

There are three spirals of large angular diameter in the South Galactic Hemisphere for which so far there is no record either of stars involved or of spectrum shift. These are N.G.C. 55 (25′), 247 (20′) and 300 (20′), all of them not far from the South Galactic Pole. Like N.G.C. 253, which is similarly situated, they are of the condensed type, 300 especially containing many starlike points in the outer regions. N.G.C. 55 and 300 are too far south for the Mount Wilson reflectors, although N.G.C. 247 was photographed (but not published as a photograph) at the Lick Observatory. They have, however, been photographed at Helwân. From their large angular diameters they must be classed amongst the "giant" spirals, and like N.G.C. 253 (22′) are probably all within a radius of 700 kiloparsecs. Within this radius all except four are in the South Galactic Hemisphere, which also contains those of largest angular diameter in the sky. The four in the North Galactic Hemisphere (N.G.C., 2403, 5194, 5457 and 4449), given by Hubble as within this radius, are, with the exception of N.G.C. 2403, of small dimensions compared with the southern systems (see fig. 2). Altogether twenty-two systems lie within the sphere of 1000 kiloparsecs, which comprises $4{\cdot}19 \times 10^9$ cubic parsecs.

TABLE II

N. Galactic Hemisphere			S. Galactic Hemisphere		
		Ang. Diam.		Ang. Diam.	
N.G.C.	3031	16′	L.M.C.	420′	
Spirals	3627	8	S.M.C.	186	
Spirals	4826	8			
Spirals	5055	8	N.G.C. 55	25′	Spirals
Spirals	5194	12	224	140	Spirals
Spirals	5236	10	247	20	Spirals
Spirals	5457	16	253	22	Spirals
			300	20	Spirals
Irr.	4214	8	594	60	Spirals
Irr.	4449	3·5	628	8	Spirals
			2403	16	Spirals
	Mean	10′	2903	12	Spirals
			7331	9·5	Spirals
			6822	20	Irr.
			Mean	32′	

The difference in mean angular diameter between the North and South Galactic Hemispheres is owing to the southern systems being both nearer and of greater actual diameters than the northern.

Spirals from 10′ *to* 16′ *in Diameter*

The foregoing list is based on Hubble's estimates derived from stars of various types which are found in the Mt. Wilson photographs down to the 19th magnitude. In addition to these there are ten edge-on spirals in

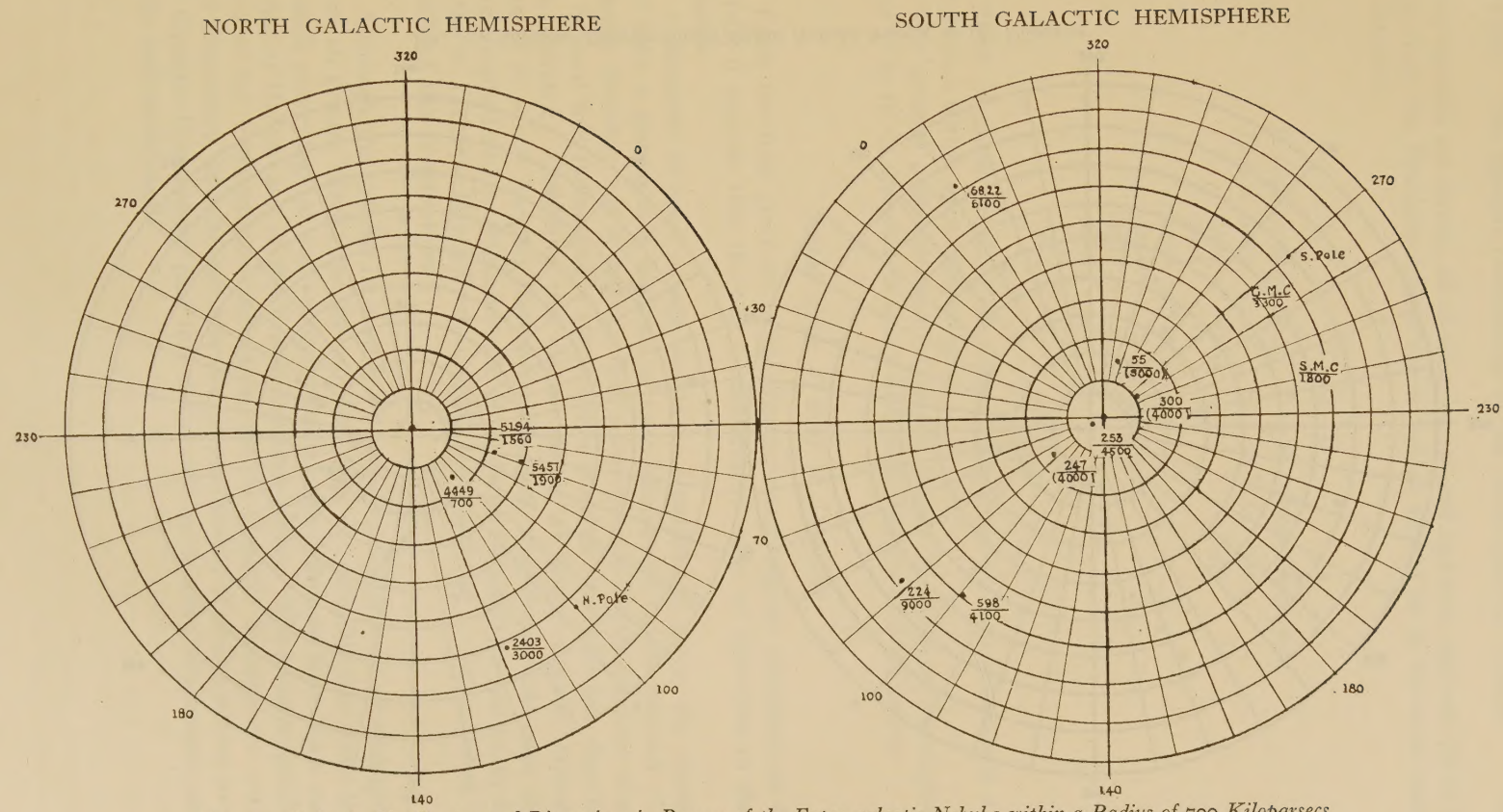


FIG. 2.—*Galactic Distribution and Dimensions in Parsecs of the Extra-galactic Nebulæ within a Radius of 700 Kiloparsecs*

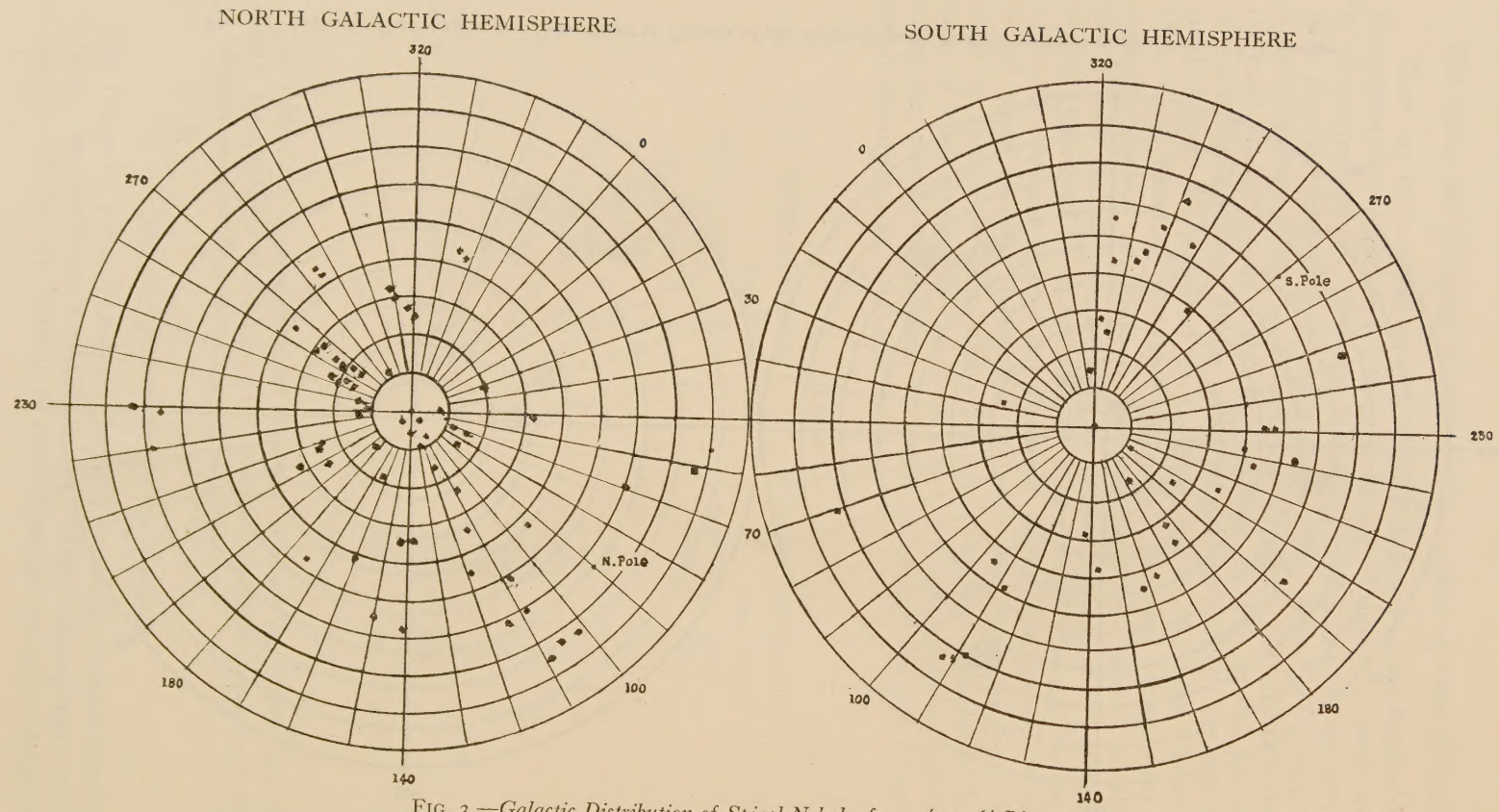


FIG. 3.—*Galactic Distribution of Spiral Nebulæ from 5′ to 16′ Diameter*

which no stars are shown, all of them of 10′ and upwards, and one (N.G.C. 6744) from the Franklin-Adams charts, which should be of the same order of distance.

TABLE III

N. Galactic Hemisphere		S. Galactic Hemisphere	
N.G.C. 2683	10′	N.G.C. 891	12′
3109	10	6744	12
3628	12		
4236	10		
4244	13		
4517	10		
4565	15		
4631	12		
5907	11		

Most of these probably lie within the radius of 1000 kiloparsecs and all of them within 1500 kiloparsecs.

The general preponderance of spirals in the N. Galactic Hemisphere from 5′ to 16′ in diameter is now a distinctive feature of distribution.

Spirals from 5′ to 9′ in Diameter

From the data given as to the distances and angular diameters of the spirals, it appears that there is a considerable range of diameters in these systems.

A diameter of 6000 parsecs would be considerably above the average, and such a system at a distance of 4000 kiloparsecs would subtend 5′ in angular diameter. It is unlikely that many systems of this diameter would lie beyond this radius and a considerable number would be less than half this distance. Including the eleven spirals of larger angular diameter than 9′ in which no stars have been detected, sixty-one spirals have been photographed and catalogued in the N. Galactic Hemisphere and thirty-five in the S. Galactic Hemisphere, ranging from 5′ to 16′. Fig. 3 shows the details of this distribution.

Although the nebulæ in northern declinations have been photographed in much greater detail than the southern, it is not probable that more than a small percentage of such comparatively large diameters have been overlooked at Helwân and on the Franklin-Adams plates. The great preponderance of the extra-galactic nebulæ in the S. Galactic Hemisphere within 700 kiloparsecs, and the considerable preponderance of such systems in the N. Galactic Hemisphere past this radius and up to 4000 kiloparsecs, seem to be well established.

THE ATMOSPHERIC DISTORTION OF STAR OBSERVATIONS FOR POSITIONS AND TIME.

A. J. Bamford, Ph.D.

The main contention that I wish to advance in this paper is that an appreciable proportion of the small variations that occur in astronomical observations for position, and which are now classed as accidental, admit of being classed as systematic with a meteorological explanation.

Although the quantities involved are small, this is more than an academic question, because if we believe that the variations between the members of a set of clock stars, or between longitude determinations on different nights, are accidental, we are justified in taking the mean of such observations as the best available approximation to the truth, and in feeling increased confidence in its accuracy if its probable error as deduced by least squares is small, whereas, if we accept the possibility of a meteorological distortion, we may have to accept unusually close inter-agreement as being itself a suggestion that the normal accidental variations have been combed out by a uniform distortion, which has distorted all equally, and so distorted their mean value.

The majority of the points made in the earlier part of this paper have already been made in principle in the *Ceylon Journal of Science*, Section E, vol. i, Part 2, "On the Variation of Clock Star Observations with the Wind" and "Longitude Determinations at Colombo, with special reference to the Distortion of Time Observations by Meteorological Causes," and Part 3, "On the Distortion of Clock Star Observations by Meteorological Causes." In the present paper it is possible to summarise them and to include results since the publication of these papers. The explanations now put forward are not merely devised to explain a completed set of observations, but are explanations to which I was committed several years ago on the strength of observations prior to that date, and which have received support from observations made since then.

Theodolite Observations.—I first realised the inadequacy of the attention given to refraction in astronomical measurements for position when engaged in theodolite work in Syria and Kurdistan in 1919.

In this work the usual precautions were taken in balancing stars, and refraction corrections were applied from surface readings of temperature and pressure (aneroid). It was found that northern stars usually gave higher latitudes than southern ones, and corresponding variations occurred in the time as determined by east and west stars.

In several cases I took observations on the same site on more than one night, using practically the same stars, and got decidedly different values from a particular star with very similar values for the latitude from the

mean of north and south stars, while the difference between east and west time stars varied correspondingly.

The bulk of the difference might have been due to flexure, or to any other cause that consistently overestimated the altitude, but the variation between its values on consecutive nights, in cases where the theodolite was not overhauled in the interval, does not lend itself readily to flexural explanation, and seemed more likely to be due to differences between the actual refraction and that adopted on the strength of the surface temperature and pressure.

Numerical details are not given here, but can be found in the papers referred to above. Peculiar interest attached to a night at Tel-Abiad from which a few figures are quoted: North and south stars were observed at altitudes 37° and 43° within a few minutes of each other. They gave latitudes differing by 11″·9 and a mean value of 36° 42′ 17″·7. East and west stars at a mean altitude of 46° were then observed and gave a difference of 0·87 secs., which for the stars in question can be accounted for if the altitude error of each was ½(10″·3). As these stars were a trifle higher than the latitude stars, the errors 11″·9 and 10″·3 are virtually equivalent.

It was not possible to get more latitude stars immediately, but after two hours a north star at altitude 55° gave the latitude as 36° 42′ 19″·4, or only 1″·7 above the previous mean. Clock stars immediately after it differed by only 0″·25. These were also at a mean altitude of 46° and demand an error in their altitude of ½(3″·0), which follows nicely on the 1″·7 just before. After the time stars a south latitude star was observed as low as 27°, and gave 36° 42′ 17″·8, or practically identical with the mean obtained at the beginning of the night's work.

The deduction is obvious. At the beginning, altitudes of about 40° were all in error by about 6″. Two hours later this was reduced to 1″·7, then to 1″·5, and later still it had collapsed to nothing, even when a rather low star was used. The instrument had not been dismounted in the interval. It seems unlikely that flexure would vary thus in 2½ hours, but it seems very likely that over semi-desert the change in actual refraction should differ by as much as 6″ from the change in assumed mean refraction given by the change in surface temperature and pressure, which amounted to about 1″.

The consistency of the difference between north and south stars and between east and west ones does not postulate a tilt in the surfaces of equal refractive index, but the change in that difference suggests a rapid variation in the lapse rate of refractive index with height above the Earth's surface, which is unlikely to have occurred evenly. A slow general increase in the density of the air might be due to a uniform cooling all round, but a rapid change probably implies the moving up of masses of colder or warmer air from a particular direction, and consequent unevenness in the optical stratification in different directions, although the accuracy of a 5-inch theodolite might be insufficient to be convincing on this point alone.

A practical corollary from the Tel-Abiad observations is worth calling attention to. The ordinary rule that states that in observations for latitude by circum-meridian stars, north and south stars should be balanced, requires

an addition. They must either be balanced quickly, or, if that is not possible, clock stars can be observed at the time of each latitude observation, and the east and west differences so obtained can be used to correct the adjacent latitude observations.

It is worth noting that my determination to follow up the subject more fully when I had the advantages of a fixed observatory was arrived at from theodolite experiences alone, at a time when upper-air work did not play the part in meteorology that it does to-day. It was also prior to the meetings of the Astronomical Union and Geodetic and Geophysical Union in Rome in 1922 at which one of the points whose study was recommended was "Atmospheric and Local Disturbances in the Determination of Time." At that meeting Major Bowie suggested that "fixed observatories, with buildings round the instruments, might suffer from winds which gave irregular lateral effects." I went further, and suspected lateral effects in the Hedjaz desert and on the banks of the Euphrates, without buildings.

Preliminary Work at Colombo

Site of the Observatory.—Before proceeding further it is desirable to describe the position of Colombo Observatory. Its latitude is given in the current *Nautical Almanac* as 6° 54′ 18″ north, the custom adopted by many observatories of stating the latitude to an accuracy of 0″·1 having been intentionally departed from.

Colombo is on the west coast of Ceylon, which island is near the southern limit of the monsoon area. In view of its proximity to the equator it experiences the vigorous convectional thunderstorms of a tropical island, and its climate may be described as a compromise between the tropical and monsoonal types.

The actual site of the observatory buildings is about a mile and a half east of a coast-line which runs approximately north and south. A bench mark on the verandah is 21 feet above mean sea-level, and the ground in the neighbourhood is fairly level. In addition to the observatory compound, open surroundings, with but little variation in level, are provided by the proximity of a golf-links, though there is a distinct belt of houses and coconut trees nearer the coast. The main bulk of Colombo lies north of the observatory, the so-called Fort, which contains the largest buildings, being a little over 3 miles away. Inland the low country extends for about 30 miles, after which the hills rise to over 8000 feet, the summit of Pidurutalagala being about 70 miles from the coast.

West of Ceylon the Arabian Sea stretches to the coast of Africa, a slight interruption being provided by the Maldive Islands about 400 miles away.

The south-west monsoon thus reaches the Ceylon coast after experiencing but little interruption, and the site of the observatory is such that a difference of a few degrees in the direction of the pressure gradient during the monsoon indicates practically no difference in the previous life-history of the air currents that approach it.

Without postulating anything as to whether atmospheric distortions are

greater or less at Colombo than elsewhere, the regularity of the seasons at Colombo certainly indicates that it is an exceptionally suitable place for such an analysis.

Probable Errors by Least Squares.—The first attempts at Colombo to follow up the ideas that had suggested themselves in the Hedjaz consisted in measuring the closeness of the agreement of the values of clock error as found from different stars on each night, and comparing their consistency with the corresponding surface wind.

The method was as follows: Clock stars were observed at Colombo from 1921 onwards through a transit instrument by Messrs Cooke with a 4-inch object-glass and electric travelling micrometer, whose breaks were recorded on a Borrel chronograph. In the first analysis groups of not less than four consecutive stars on the same face and by the same observer were considered. Thus six stars with a reversal midway would have been ignored, and eight stars, four on each face, would have counted as two groups, provided all the stars in each group were by the same observer. For each group the probable error of the mean was estimated by least squares, while the corresponding wind was read off a self-recording anemometer, though only to the precision of the nearest Beaufort scale number. Observations were not made with the wind above Beaufort 4. Various methods were used for analysing the results, and details were published in the *Ceylon Journal of Science* (Section E, vol. i, Part 2, pp. 120–122). All gave the same result, namely, that the agreement between clock stars improved as the wind strengthened.

The following example is given to show the numerical range: All the groups were arranged in ascending order of the magnitude of their probable errors. The list was then broken up into steps of twenty each, and for each step the probable errors and corresponding winds were averaged. In one year (1923) the probable errors of the successive steps, in seconds of time, were 0·005, 0·010, 0·014, 0·021 and 0·035 (13 groups only). The corresponding winds were 1·75, 1·40, 1·15, 1·12 and 0·96.

I imagine the explanation is that calmness allows convection currents to have more effect than is the case when the monsoon is combing everything out into parallel layers. When there is but little wind the convection currents that are inevitable in a tropical climate provide irregularly distributed columns of varying density, and hence irregular distortion, and a comparatively large probable error, as measured by least squares. This idea is confirmed by the fact that in 1923 there is one, and only one, "calm" among observations with a P.E. less than $0^{s}\cdot008$. On that day (and on the previous one) the sunshine recorder had been practically out of action all day—a most unusual thing in Colombo.

Star Groups Analysed in Terms of Zenith Distance.—For each group of stars I took the mean value of the clock error and expressed the values from individual stars as offsets from it. These offsets were placed in columns according to their azimuth coefficients. After doing this for a number of star groups the offsets in the different columns were averaged and, for the period concerned, the mean offsets of clock errors were plotted against

azimuth coefficient. This has been done for several periods, and in each case it has been found that, in the south-west monsoon, with a definite pressure gradient across the meridian, a curve with definite convexity was obtained with its most positive values near the zenith (where the azimuth coefficient is zero), while at other seasons this was not so. Several tables and curves on this point have appeared in the *Ceylon Journal of Science*, but to avoid overcrowding this paper I only reproduce in it figures and curves for the south-west monsoon of 1928, and for the inter-monsoon and north-east monsoon period that preceded it.

Table I

Mean Variations of Clock Star Determinations in Seconds of Time

Azimuth Coefficient	Other Seasons					S.W. Monsoon				
	1927 November–1928 April					1928 May–September				
	Steps of 0·1		Steps of 0·3			Steps of 0·1		Steps of 0·3		
	Offset	Number of Stars	Offset	Number of Stars	Average	Offset	Number of Stars	Offset	Number of Stars	Average
N.										
Over ·7	−·05	14	−·01	37	−·0003	−·06	10	−·32	31	−·0103
·6–·7	+·09	9	+·04	41	+·0010	−·20	11	−·28	28	−·0100
·5–·6	00	18	+·10	41	+·0024	−·02	7	−·14	34	−·0041
·4–·5	+·01	14	−·15	57	−·0026	+·08	16	+·13	33	+·0039
·3–·4	−·16	25	−·11	53	−·0021	+·07	10	+·15	29	+·0052
·2–·3	+·04	14	−·10	54	−·0019	00	3	+·10	29	+·0035
·1–·2	+·02	15	+·45	56	+·0083	+·03	16	+·16	33	+·0048
0–·1	+·39	27	+·39	56	+·0070	+·13	14	+·17	45	+·0038
0–·1	−·02	14	+·16	51	+·0031	+·01	15	+·13	34	+·0038
·1–·2	−·21	10	−·20	38	−·0053	−·01	5	+·01	36	+·0003
·2–·3	+·03	14	−·47	44	−·0107	+·01	16	+·08	35	+·0023
·3–·4	−·29	20	−·24	44	−·0055	+·08	14	+·08	53	+·0015
·4–·5	+·02	10	−·09	56	−·0016	−·01	23	−·01	48	−·0002
·5–·6	+·18	26	+·28	49	+·0057	−·08	11	−·03	40	−·0007
·6–·7	+·08	13	+·13	43	+·0030	+·06	6	−·07	21	−·0033
Over ·7 S.	−·13	4	−·18	21	−·0086	−·05	4	−·04	14	−·0029

In Table I the sum of all offsets are given in steps of 0·1 in the azimuth coefficient, but these steps are rather short for smooth plotting. The table also contains figures derived from consecutive steps of 0·3 in the azimuth coefficient, and points on the curves in fig. 1 are obtained by plotting the results from these overlapping intervals of 0·3.

The ordinary corrections for collimation (including aberration where appreciable), level and azimuth had of course been applied, and if they were adequate the curve at any season should be a horizontal straight line. Additional accidental errors should show evenly as plus or minus variations distributed erratically along the axis of x. With this calibration the effect

of a small improvement in the azimuth correction would be to rotate the whole diagram slightly, and so make an oblique line through the origin the new axis of x. The main distinction between the presence or absence of a definite convexity in the curves would be unaltered by such a rotation.

An error in the collimation correction might give a continuous convexity, but as the sum of these corrections in the two positions of the instrument is

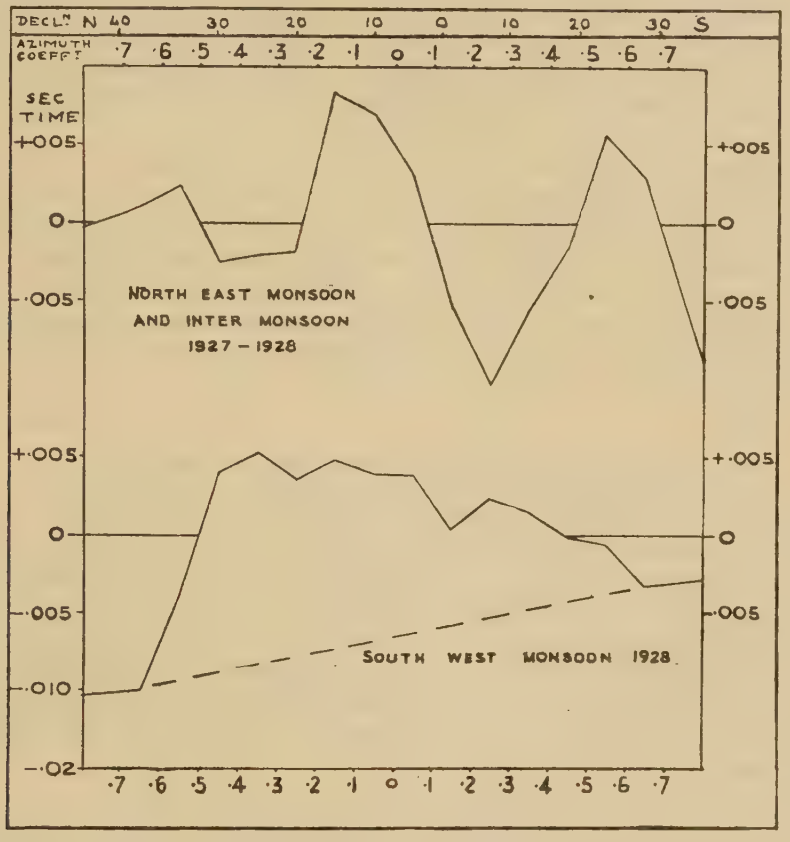


FIG. 1.—*Variation in Clock Stars with Zenith Distance.*

The horizontal scale is calibrated in coefficients of the azimuth correction. Notice the continuity of the curve in the south-west monsoon compared with its irregularity at other seasons.

governed by the width of the break on the travelling micrometer, such a fault should give opposite convexities in the two positions, whereas separate plotting gives parallelism (*C.J.Sci.*, Section E, p. 125, plate 2).

In fig. 1 questions of personal equation and clock rates do not come in seriously, as each item is a complete whole in itself, completed by one observer, within a short time.

The fact that during the monsoon zenith stars tend to be observed relatively later than low ones does not indicate which group is the more absolutely correct, but it would certainly not be surprising if zenith stars were less distorted by refraction than low ones. Hence a promising

hypothesis (admittedly not a unique one) to explain fig. 1 is to assume that during the monsoon all stars tend to be observed early, those near the zenith being least affected.

The classification by average probable errors of groups has already suggested the unifying effect of the combing out of the air that takes place in presence of strong wind, such as occurs in the monsoon. Table I and fig. 1 will also be explained if we can believe that during the monsoon the refractive index of the air increases from west to east across the meridian. Such a distribution would make all stars be observed too soon, and, just as in the case of collimation error, the effect will be more marked in the case of stars whose declinations are considerable.

To test this hypothesis, the next thing to do appears to be to consider what atmospheric structure would give the observed results, and whether the existence of such a structure is indicated on meteorological grounds.

At Colombo, where declinations and zenith distances only differ by 7°, a bank of high optical density east of the meridian during the monsoon would give the required result. At this stage it is not necessary to postulate the relative importance of pressure, temperature, humidity, etc. in producing this density.

Structure of the Atmosphere during the Monsoon

Consider next the meteorological possibility of such a bank. At first sight there appears to be a pressure gradient in the other direction, *i.e.* with higher pressure on the west. The ordinary pressure gradient as read from isobar charts in the south-west monsoon certainly shows higher pressure west of Ceylon than east of it, but in such a bird's-eye view of southern Asia we think in gradients of the order of one millibar per hundred kilometres, and a very little calculation will show that such a change in pressure will not alter the refractive index enough to produce anything like the variations observed.

From pilot balloon observations we know that, during the south-west monsoon, the wind at the surface at Colombo is decidedly less than that at a kilometre above it, while the direction is, as might be expected, similar, but a little more at right angles to the isobars near the surface. The suggestion is that we may regard the surface wind as the reduced lower flank of the upper one, the reduction being affected by the friction of the surface of the globe. In passing over the sea west of Ceylon such friction exists, but its amount becomes greater as soon as we pass from sea to land, and consequently the surface winds become less. We have then the meteorological fact that near the surface at Colombo more air is being brought from the west in the lower levels than is being carried away eastward at those levels. The result must be a congestion of air where the velocity begins to change, which congestion tends to adjust itself by ascent. However, at the moment we are more concerned with the congestion than its corollaries, and, as the ascent demands reorganisation of upper-stream lines, it will only take place when it has become the path of least resistance, or, in other words,

when the congestion is sufficient to demand some release. There is ample meteorological evidence for the ascent,* so that we can fairly postulate the congestion—particularly at times when either the monsoon is increasing in strength, or the check that it experiences on reaching the land is increased in any way.

Fig. 2 is a section from west to east, and makes an attempt to depict what is happening, the congested area being shown in section by dots, while the resulting ray from a star, as observed in the transit instrument, is also shown.

If fig. 2 is a correct picture of what is happening, it explains Table I

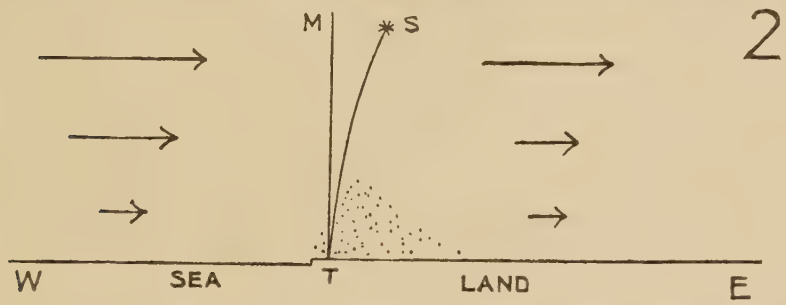


FIG. 2.—*Looking North during South-West Monsoon, showing reduced Wind over Land and consequent banking up of Air immediately East of Coast.*

MT—*Vertical ray through transit instrument.*
ST—*Path of ray from star to transit instrument.*

and fig. 1, and also postulates that all stars tend to be observed too early during the monsoon.

Having got a suggestion as to the structure from meteorological grounds that is consistent with the star work up to 1926, the next stage is to test it in conjunction with the subsequent longitude determinations.

Longitude Determinations at Colombo, 1926–1928

Regular observations of the Bordeaux vernier signal were commenced at Colombo in 1926 (September), and of the Rugby one from 1928 (January).

The effect of the wireless longitude determinations, that were commenced during the period of international co-operation in 1926 October–November, was to show that the previously accepted value of the longitude of Colombo was too far east by an amount of the order of half a second of time—a result similar to that found in India, and farther east at Hong Kong. However, the question now under consideration is not so much the amount of that alteration, but the variations between the different determinations of it made from each set of clock stars, and the possibility of correlating those variations with the weather at Colombo.

Throughout this paper longitudes are expressed as additions to the value

* "On the General Circulation of the Air over Ceylon," *Bulletin No. 4 of the Colombo Observatory*; "On the Climate of Western Ceylon," *Ceylon Journal of Science*, Section E, vol. i, pt. 3.

5^h 19^m $28^s.60$, greater positive values denoting a greater numerical amount for the easterly longitude, and corresponding to the effect of observing stars earlier at Colombo.

Connection between Longitude and Pressure Gradient.—If the atmospheric banking up, and consequent distortion of clock-star observations that has been postulated above, is taking place, we should expect the greatest values of the longitude when it is most pronounced. As the banking up is primarily due to the monsoon advance being checked, we should expect it to be most marked on days when the monsoonal advance is strongest, and hence the checking process has most scope.

This suggests a connection between the star observations and monsoonal wind strength. Direct measurements of surface wind are inadequate for this purpose, since not only is the surface wind a very varying quantity, but in particular it does not discriminate between a velocity that is the lowest (and slowest) part of a general monsoonal drift, extending to several kilometres in height, and a sea-breeze effect that may give the same velocity and direction near the ground, but does not extend upwards to more than half a kilometre. Hence for the present purpose it seems safer to ignore surface anemometer readings and measure the general monsoonal drift in terms of the pressure gradient across Ceylon as a whole.

In Table II and fig. 3 the mean values of longitudes are given in terms of gradient. It will be found throughout that, as we pass from left to right, there is a successive increase in the longitude corresponding to steeper gradients from the south-west. This is, I submit, too marked to be fortuitous, and is direct evidence that, in presence of a definite south-west monsoon gradient, this distortion does occur, and that its amount increases with the strength of the monsoon. The longitudes used in this table and graph were obtained by comparing the Colombo star observations with European time-signals. In 1927 the Bordeaux verniers were used, and the corrections published in the *Bulletin Horaire* have been applied. In 1928 the Rugby verniers were used and the corrections as determined at Greenwich, and published in *Admiralty Notices to Mariners*, applied. Gradients were determined from the mean of the four daily barometer readings at Colombo, Hambantota and Trincomalee on the days in question, no use being made of the autographic charts. In the south-west monsoon months these four values are often very similar in both strength and direction during any particular day, and admit of fairly rigid classification. The column headed "Gradient from N.E." is less rigid, and includes days when the gradient varies from north-west to north-east, as it frequently does at the time of year concerned.

Gradients of less than 0·5 millibar per 100 kilometres are grouped as smooth, and gradients between 0·5 and 1·5 mb./100 km. as light. For each period observations made with gradients of 1·5 mb./100 km. and over are divided into two groups, moderate and steep, such that there are about the same number of observations in each group, which means that the dividing line between the two is taken at different places in the different periods, according to the actual distribution of gradient strength concerned. There

is no loss of rigidity in this, as for each group the mean value of the gradient is plotted explicitly. This method was adopted because the main interest attaches to gradients of over 1·5 sec./mb./100 km. It is not essential, because alternative groupings gave very similar results.

TABLE II

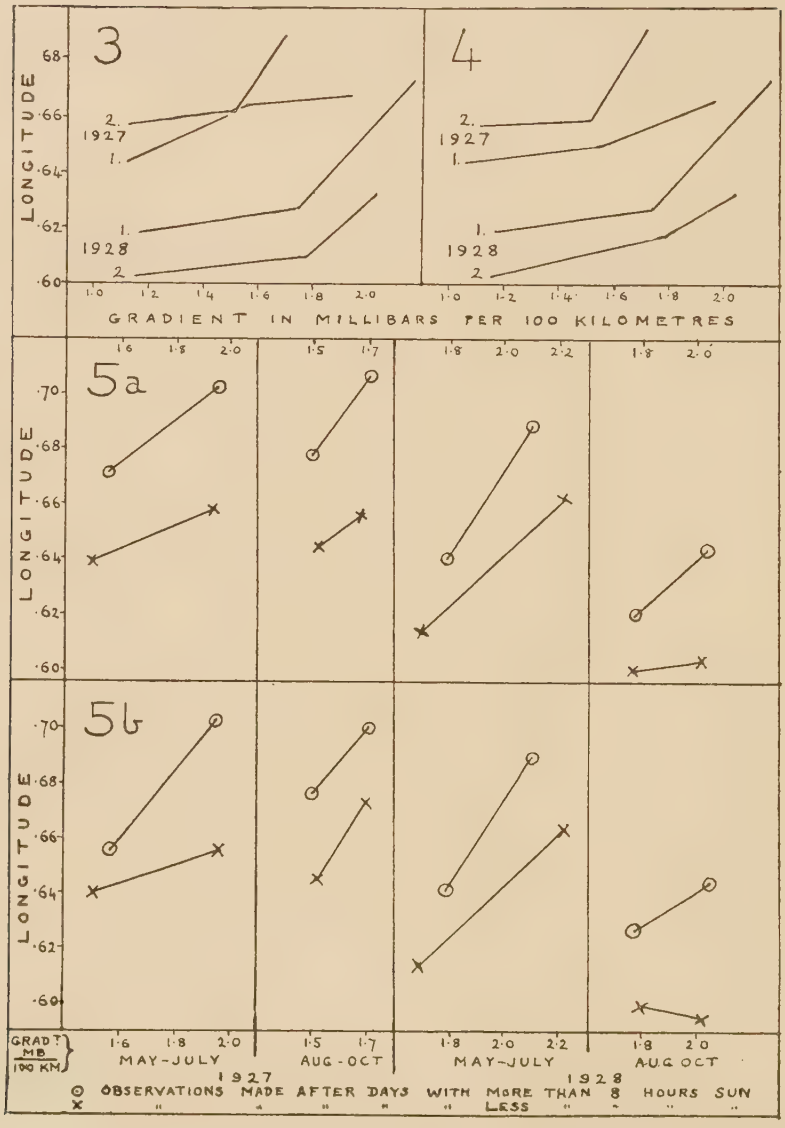
Mean values of the E. longitude of Colombo expressed as offsets from the value $5^h\ 19^m\ 28^s.6$ *classified in terms of pressure gradients which are given in millibars per* 100 *km. The number of nights of observation in each group is shown in brackets. The unit of longitude differences is* $0^s.001$

	N.E.–N.W. 0·5–1·0	Calm < 0·5	South-west Gradients					
			Light, 0·5–0·4		Moderate		Steep	
			Longitude (Unit $0^s.001$)	Gradient	Longitude	Gradient	Longitude	Gradient
1927								
Jan.–Apr.	22 (16)	41 (25)	65 (12)	...	...	...	...	...
May–July	...	...	45 (10)	1·06	65 (9)	1·55	68 (9)	1·94
Aug.–Oct.	...	...	59 (22)	1·12	62 (10)	1·51	90 (9)	1·70
1928								
Jan.–Mar.	−42 (32)	22 (13)	33 7	...	...	...	...	...
May–July	...	...	19 (8)	1·16	28 (8)	1·74	74 (9)	2·17
Aug.–Oct.	...	...	3 (3)	1·15	10 (12)	1·77	33 (11)	2·03

Fig. 3 shows that in each of the four curves summarising the work of three months an increase in steepness of gradient is associated with more easterly longitude, *i.e.* the result we should expect if stars are observed too soon. Further, in three of the four curves the rate of distortion increases with the gradient.

The mean of the four curves gives $0^s.09$ as the increase in longitude, corresponding to an increase of 1 mb. per 100 km. in the section from moderate to strong gradients. As an alternative grouping the left-hand point (light gradient) may be compared with the mean of the other two (moderate and strong). The result in each case is a rate of 0·03 or 0·04 sec./mb./100 km.

It will be noticed that in the above all the emphasis is on the comparison between groups of stars observed under different weather conditions within



FIGS. 3 *and* 4.—*Longitudes from groups of observations made under different conditions of pressure gradient and previous sunshine. (The longitude scale is in decimals of a second of time. A basic value of* $5^h\ 19^m\ 28^s$ *is assumed throughout.) Each curve is fixed by three points and refers to a period of three months, the figures* (1) *and* (2) *denoting the first and second halves of the monsoons in question. In each period the observations have been divided into three groups in ascending values of the associated pressure gradients, and the mean values of the longitudes for each group plotted against the mean values of the gradient.*

FIG. 5 (*a*) *and* (*b*).—*Observations have been divided into two main classes, according to whether they were made on days on which there had been more or less than* 8 *hours of sunshine. In each class and in each period they have been divided into two groups, namely, those made under greater and lesser pressure gradients. Corresponding mean values of longitude are plotted against mean values of gradient.*

the same period, and not on the different values obtained during different periods.

This is intentional, because the variations between those values depend not only on meteorological eccentricities at Colombo, but also on other distortions due to non-meteorological causes (*e.g.* movement of pole), and possibly to meteorological causes whose seat is not at Colombo. These complications are largely smoothed effects which can be ignored in comparisons between consecutive observations, but could not be ignored in comparisons over longer periods.

Comparisons over shorter periods than three months would be preferable if there were sufficient observations. However, to make the systematic errors apparent, enough observations must be used in each group to give the accidental, non-meteorological errors a chance of cancelling out. Hence in this first grouping by gradients it seems best to use periods of as long as three months.

Table II shows that longitudes obtained at the beginning of each year were less than those determined during the monsoon. This may be in part due to meteorological causes, but only the monsoonal curves are given in fig. 3 because of the unknown values of the other distorting influences.

It is worth noting that different classifications from those used in Table II and fig. 3 were adopted in some of my previous publications, but gave the same result in the main point, *i.e.* the increase of longitude with gradient. This fact is an accidental confirmation that that result was not obtained by any special choosing of the steps in gradient. In a particular case it might be conceivable to obtain a spurious result by a fortuitous choice of intervals. It would hardly be possible for this to occur in each of two rigid methods of choosing them.

The point may be carried further. In 1928 I published (*C.J.S.*, p. 142) results for 1927 which included the corrections to the Bordeaux verniers as broadcasted the next day. The corrections published in the *Bulletin Horaire* differ considerably from the above, and are used in this paper, yet the two different sets of figures agree in giving similar mean relationships between longitude and gradient. The explanation is simple—the *Bulletin Horaire* corrections have nothing to do with the reception at Colombo. In terms of Colombo weather the inaccuracies due to their omission were accidental, not systematic, and as such tended to cancel out in means and allow the systematic gradient effect to show up in a classification by gradient. The effect of applying the *Bulletin Horaire* corrections, and dividing the observations into groups of approximately equal weight, has simply been to reduce the residual masking effect of accidental errors and make a relationship that could be seen in 1928 become a trifle more obvious.

Checking Force on Monsoonal Drift

In the above, the very natural assumption has been made that the steeper the monsoon gradient the greater will be the effect due to checking it, but it is worth considering how the checking force may vary. To a great extent

it is the mechanical obstruction of hills, and as such constant. The frictional checking force due to surface vegetation is nearly constant, and more so in the tropics than in a country with well-defined summer and winter; but there is also the question of the difference in checking power between still air and vigorous convection currents over the land. The checking power of convection currents is considerable, and its effects on the monsoon at Colombo show clearly in connection with the rainfall there. (This point will not be elaborated here, but has been dealt with in a paper on the "Climate of Western Ceylon" (*Ceylon Journal of Science*, Part 2).) Hence it might be expected that the larger values of the longitude will show a connection, not only with increased monsoon gradient but also with increased convectional check. The nearest approach to an index of the convectional activity is the duration of bright sunshine. In Table III the mean values of the longitude in the various periods, found under definite south-west monsoon gradients, are subdivided according to whether the number of hours of bright sunshine on the day preceding each evening on which stars were observed was greater or less than 8. It will be seen that for gradients of over 1·5 mb./100 km. greater amounts of sunshine, which suggest greater convectional obstruction, are always associated with greater longitudes.

TABLE III

Longitudes classified in terms of gradient and hours of sunshine. Variations are expressed as offsets from the value $5^h\ 19^m\ 28^s.6$ *in terms of the unit* $0^s.001$

Gradient		Slight		Moderate		Steep	
Hours of Sunshine		Over 8	Under 8	Over 8	Under 8	Over 8	Under 8
1927							
May–July	Longitude	32	51	72	40	102	59
	Gradient	1·08	1·04	1·56	1·50	1·95	1·94
	Number	3	7	7	2	2	7
Aug.–Oct.	Longitude	55	66	78	45	107	57
	Gradient	1·17	1·03	1·50	1·52	1·71	1·68
	Number	14	8	5	5	6	3
1928							
May–July	Longitude	70	−32	41	14	89	63
	Gradient	1·21	1·10	1·79	1·69	2·10	2·22
	Number	4	4	4	4	4	5
Aug.–Oct.	Longitude	−10	10	20	0	44	5
	Gradient	1·15	1·15	1·77	1·77	2·04	2·02
	Number	1	2	6	6	8	3

For mild gradients of less than 1·5 the effect is irregular. This is quite natural, since, if there were no gradient, strong convection would probably be associated with less dense air over the land than over the sea, and hence

there would be the opposite effect to that observed when the convection column acts as a check to a strong monsoonal drift. With a weak monsoonal drift intermediate between these opposite effects the resultant effect on the longitude will also be irregular. Fig. 5 (*a*) shows the plotting of Table III for moderate and strong gradients, and brings out the way in which, under these gradients, the longitudes determined after sunny days are in each period greater than those after dull ones, while the general slope of increased longitude with steeper gradient is maintained.

The diagram also brings out the fact that in each period not only is a more easterly value of the longitude obtained after the sunny days, but the rate of its increase with increasing gradient is also greater on these days. That this further point of detail shows in each of the separate four periods is an extraordinarily complete confirmation of expectation. The abnormality shown in fig. 3 for the period 1927 May–July is explained in part by the fact that a majority of the observations made with moderate gradient were after more than 8 hours of sunlight, and of those with steep gradients after less than this amount.

The claim of connection between increased longitude and increased gradient can thus be extended to connection with both increased gradient and increased sunshine. Fortunately, it is also possible to approach the correlation from quite a different set of meteorological readings, and ones which have the advantage of enabling monthly, instead of three-monthly, periods to be used.

Relationship between Longitude and Pilot Balloon Observations.—In the description of fig. 2 the whole idea of the increased refractive index near the coast turned on the difference between the wind velocities at the surface and in the main monsoonal stream above. If we subtract the velocity near the surface from the rather greater velocity half a kilometre above it, the difference is a rough index of the retardation that is the parent of the whole effect under discussion. To be absolutely rigid we should take comparisons between the wind at these two levels, both at sea a little west of the coast and inland a little east of it, but as all that is required is an index to compare the retardation on one day with that on another, a set of comparisons all made at the same spot in the observatory compound may suffice.

The method adopted has been to take the westerly component of the wind at half a kilometre above the surface, as measured in the afternoon pilot balloon flight, and substract from it the westerly component of the surface wind, as measured at the same time by the pressure anemometer whose head is 40 feet above ground level. This difference has been adopted as an indication of the "monsoon obstruction," irrespective of how far it is caused by steep gradients or convectional checks. The refinement of using components perpendicular to the meridian is probably not very important, as the directions are so consistent.

In each month the nights on which longitude comparisons were made have been arranged in the order of the amount of difference between these wind components, and the list so formed divided in the middle. Except

in the case of two months that are referred to below, averages of both the wind differences and the longitude determinations were taken for the upper and lower halves of the list, and the results appear in Table IV and fig. 5 (*c*).

In every case that admits of such comparison, namely, the independent readings in ten different months, the same result appears—*the more easterly longitudes occur with the greater wind velocity differences*. This is too striking a result to be fortuitous, and I claim it unhesitatingly as evidence, independent of figures for pressure and sunshine, of the distortion of the clock-star observations due to meteorological causes.

TABLE IV

Longitude determinations in each month divided into two approximately equal groups corresponding to small and large excesses of the wind velocity at half a kilometre above the surface over that at the surface

	Small Differences			Large Differences			Excess of Longitude with larger Wind Differences
	Number of Observations	Mean Velocity Differences (m./sec.)	Longitude (Unit $0^s.001$)	Number of Observations	Mean Velocity Differences (m./sec.)	Longitude (Unit $0^s.001$)	
1927							
May	5	1·7	21	1	7·0	40	19
June	3	5·1	32	3	9·4	60	28
July	5	6·5	71	5	7·8	89	18
Aug.	7	3·3	21	6	6·0	28	7
Sept.	2	2·3	48	3	6·0	98	50
Oct.	4	1·6	48	5	3·8	129	81
1928							
May	3	2·4	33	3	5·9	50	17
June	2	4·2	−5	3	6·3	42	47
July	4	2·4	36	4	5·9	72	36
Aug.	4	4·6	−41	...	...	...	...
Sept.	5	2·9	33	5	4·1	67	34
Oct.	2	2·3	10	1	6·6	180	(170)

The two months whose figures do not help do not in any way contradict. In 1928 August all the velocity differences were within half a metre per second of each other, so that a subdivision was not practicable. In 1927 May on five of the six days the differences were very small, and form a natural group, while one stands out with a velocity of 7 m./sec. The longitude on that day was actually greater than on the mean of the others, so that the law is complied with, but a single determination is not an adequate basis to argue from.

I attach particular importance to the pilot balloon work, because I have

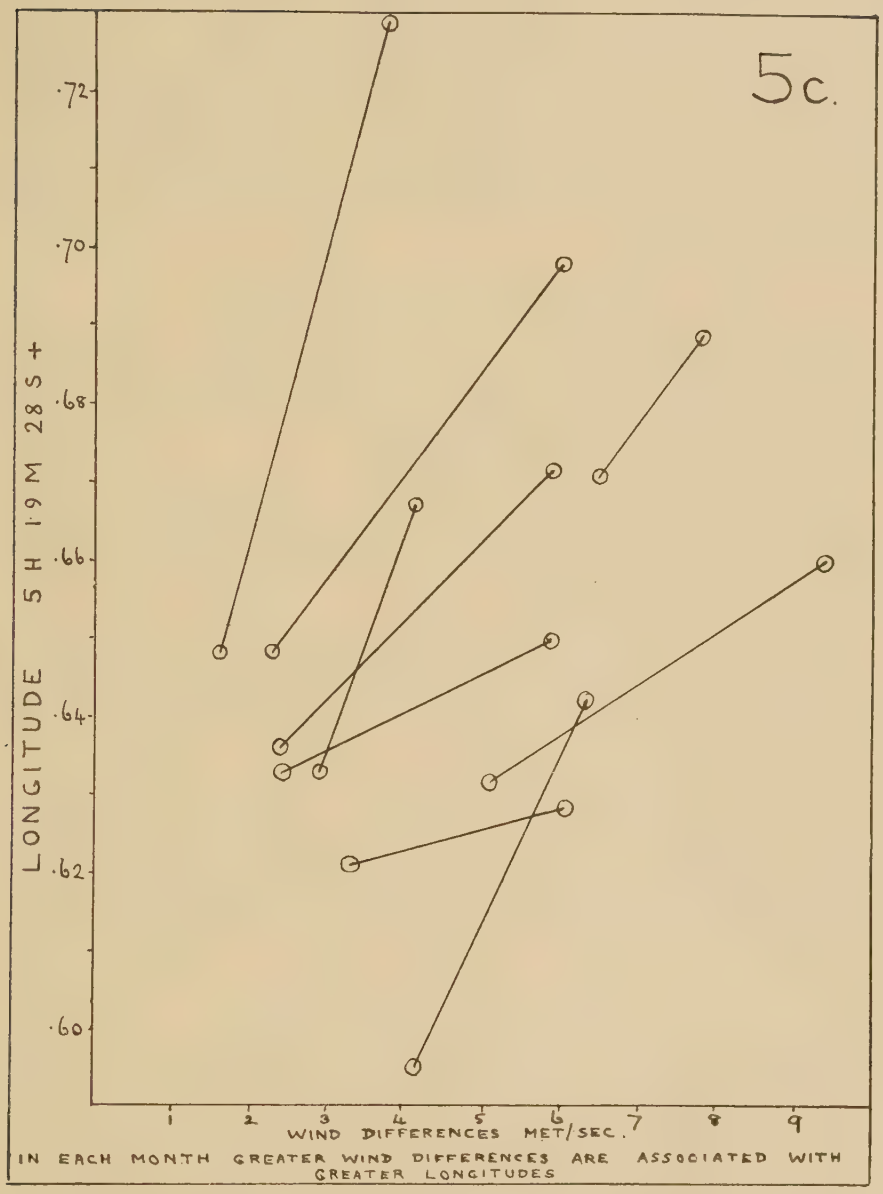


FIG. 5 (*c*).—*Longitudes as obtained in each month under conditions of greater and less change of wind velocity with altitude. Each line refers to a month's observations. Its extremities are obtained by dividing the observations into those made with greater or less values of the change between wind velocity at the surface and at half a kilometre above it. Values of this change are plotted against corresponding values of the longitude.*

frequently been met with the argument that if any real meteorological relationship existed it would have been identified in previous attempts, and its existence accepted generally by astronomers and geodesists all over the world to an extent that is certainly not the case at present.

Several of the previous attempts made elsewhere to find such a relationship prove on examination to be nothing more than attempts to connect star variations with surface wind alone. The striking thing about them is that they gave as much indication as they did, not that they failed to give more. Their inadequacy, in some instances, does nothing to discredit attempts with fuller data.

Inadequacy of Grouping by Months

Another cause that has helped to delay the systematisation of refraction errors is that attempts have been made by such methods as comparing mean effects over a month (or longer) with the means over other months, which clouds the issue with all sorts of complications.

Fig. 6 (*a*) is inserted with the deliberate object of demonstrating the inability of a mere seasonal grouping to show a meteorological connection. Most of the points in it refer to means of a month, but in some cases shorter periods are used for the sake of comparison with the diagram of levels below, which will be referred to later.

In 1927 the firm line shows values deduced from the Paris signal with the *Bulletin Horaire* corrections. In 1928 it shows values from Rugby with the Greenwich corrections. In certain months a chain line shows values to which only the Paris values as broadcasted on the following day have been applied.

It will be seen that the lines in this diagram are hopelessly irregular and utterly useless in indicating any systematic meteorological connection.

The very observations, which, when compared individually with pilot balloon results, show a consistent trend in fig. 5 (*c*), show nothing if merely assembled in such a crude form as monthly or bi-monthly averages.

The General Instrumental Question

Some people dismiss the whole subject of abnormal refraction on the ground that large personal and instrumental errors are liable to occur, and to swamp all others, to an extent that makes it useless to attempt such refinements as the search for meteorological relationships.

Prior to the introduction of the electric travelling micrometer, variations in personal equation might have led me to accept this view so far as transit instrument work was concerned, but the travelling micrometer has taken the sting out of personal equation troubles at the cost of adding another possible source of error to the instrumental equipment. Unless a great deal of care is exercised in maintaining the instrumental efficiency, especially that of the travelling micrometer, it would be idle to analyse residual errors for meteorological effects. My papers on atmospheric distortion in the

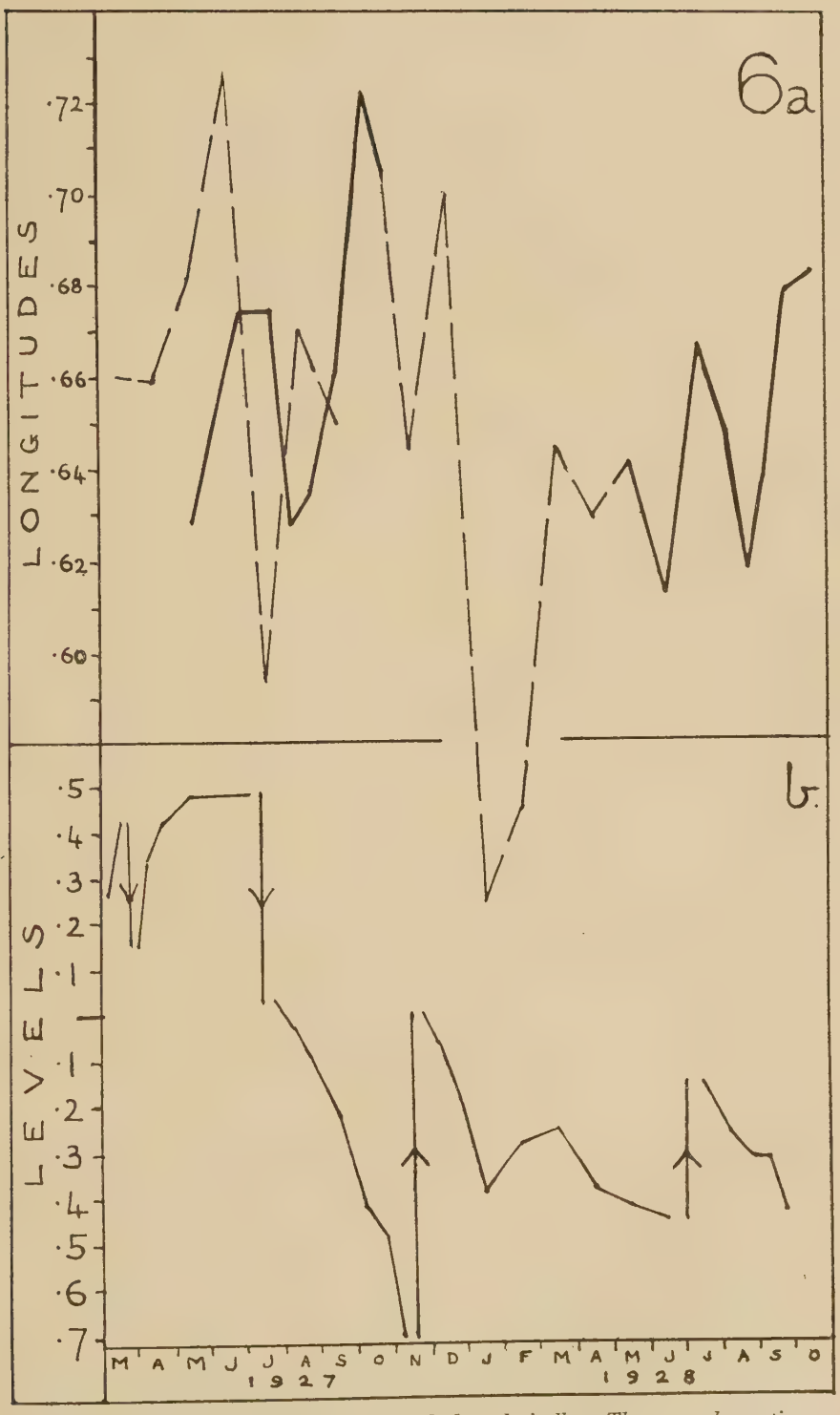


FIG. 6.—*Longitude observations grouped chronologically. The same observations that showed systematic results in figures 3, 4 and 5 fail to do so in mere seasonal grouping. The lower diagram gives mean values of the level correction, and by its lack of parallelism with the upper one shows that there was no serious error in the adopted value of the level graduations.*

Ceylon Journal of Science include references to such work as the construction of a special relay for receiving the vernier time-signals, and the effects of first repacking and subsequently renewing the spring of the micrometer (Section E, vol. i, pp. 129–131 and 228, 229). It would be irrelevant to discuss these points fully here, but the fact that they have been dealt with is worth mentioning as evidence that a close watch was kept on the instrumental side, which clears the field somewhat when looking elsewhere for explanations of residual effects that could not be explained as instrumental.

Level Errors

When I spoke before the Royal Astronomical Society in 1929, Professor Sampson expressed the opinion that anomalies of the type I was discussing could usually be traced to the level determinations. It is therefore desirable to examine the questions of whether the results at Colombo can be explained away as due to this cause.

A good deal of work had been done here on the subject of level variations on pillars before the present analysis was commenced, and a paper was published by me as long ago as 1912 in *Beiträgen zur Geophysik* on the "Slow Periodic Movements of the Colombo Seismograph Pillar." Much of the reasoning in that paper is applicable to the pillar of the transit instrument, though the amounts are likely to be smaller in the latter case. Hence it was certainly with no underestimate of the liability of pillars to move that I refrained from discussing this point more fully in my earlier papers in the *Ceylon Journal of Science*.

In all observations used in this paper, level readings were made in both positions of the instrument, and mean values are shown in fig. 6 (*b*). The fact that sharp changes which were made by levelling the axle artificially in 1927 July and 1928 June did not appreciably alter the value of the longitudes, is at once a strong confirmation of the accuracy of the adopted value of the level graduations.

It is clear from fig. 6 (*b*) that if the different nights' observations during a period of several weeks in, say, 1927 August–September are divided into two halves on the criterion of size of level error, the more positive values would be during the first half of the period. If, however, we make a similar division over a short period, when the observations were sufficiently frequent to admit of it, we shall avoid the masking effect of the steady creep and find that greater and smaller values follow each other erratically, and the mean date of the nights with smaller values will be about the same as the mean date of the nights with larger ones. Having divided the nights concerned into two groups on the criterion of size of level correction, we can find for each group the mean value of the deduced longitude or of any other connected quantity that may be relevant.

This process has been applied to successive groups throughout the period under review, the allowable duration for any group being limited by the rate of change of the steady creep of the level error, whose masking effect must be avoided.

If the level values as determined are correct, such differences as occur must be due to other causes, and hence are equally likely to be + or − when classified in terms of levels. If, on the other hand, with positive level corrections denoting an axle lower at its east end, we suspect that an algebraically large value of the level correction is really an overestimated value, it means that the nights with more positive level corrections would be nights on which the determinations of the east longitude were too small.

At the latitude of Colombo the coefficient of the level correction does not differ greatly from unity for stars that transit within 30° of the zenith,

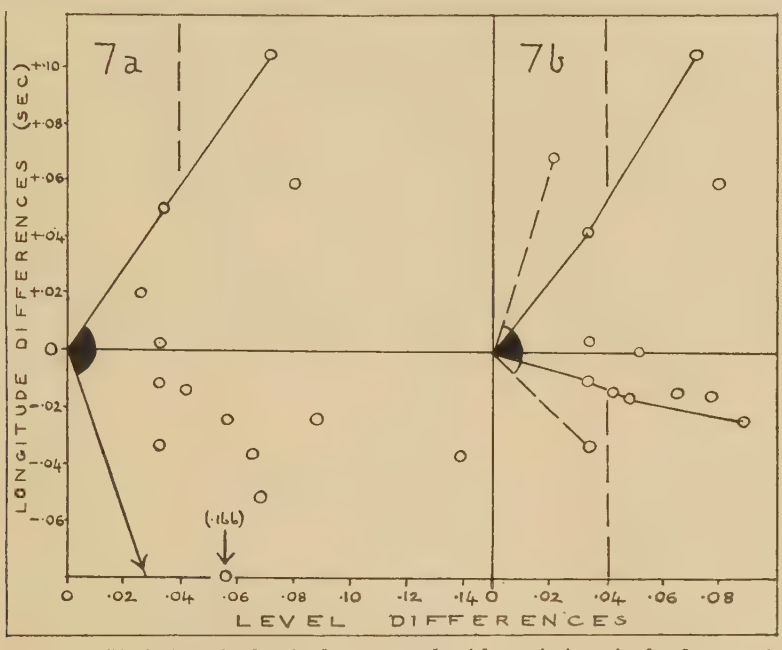


FIG. 7.—*Variations in longitude compared with variations in level correction. Points in these diagrams are obtained by dividing each group of observations into two halves, namely, those with greater and less values of the level correction. The differences between the corresponding values of longitude are then plotted against the differences of level correction for each pair.*

i.e. for the bulk of the clock stars concerned. Hence if the differences between the level corrections are plotted as x co-ordinate against the corresponding differences of longitude along the y axis, the effect of faulty level readings, if appreciable, should show in the resulting points tending to group themselves near the line $y+x=0$.

Results are given in Table V and plotted in fig. 7 (*a*), and do not show such a grouping. The points spread out in a way that does not admit of their being threaded in any simple curve or even in a small angle fan. The most that can be said for them is that in more than half the cases y is of opposite sign to x, which may be due in part to faulty level corrections (this point will be considered later), but any such effect is less marked than larger variations due to other causes.

All the observations used in Table II are included in Table V, and most

of them are plotted in fig. 7 (*a*). The ones of which no use can be made are an isolated observation in 1927 at the end of October, and those in 1928 August, which must be omitted on account of creep.

TABLE V

	Observations Grouped by Size of Level Corrections				For the Same Groups. Longitude	
	Each Group		Each Period (Both Groups)		$5^h\ 19^m\ 28^s.6$ +	
	Number	Mean Level		Difference	Each Group	Difference
		Unit $0^s.001$				
1927						
May 2–27	4 5	+530 +442	+481	88	14 39	− 25
June 13 July 11	5 5	+515 +450	+482	65	55 92	− 37
July 12–29	5 4	+ 58 + 2	+ 33	56	63 88	− 25
Aug. 2–18	5 5	− 12 − 54	− 33	42	21 36	− 15
Aug. 23–31	4 4	− 76 −102	− 89	26	40 21	+ 19
Sept. 2–28	5 4	−161 −299	−222	138	45 82	− 37
Oct. 1–9	4 3	−391 −459	−420	68	100 152	− 52
Oct. 10–16	3 3	−460 −494	−477	34	128 80	+ 48
Oct. 30	1	...	−640	...	96	...
1928						
May 5–29	3 5	−378 −450	−423	72	92 −10	−102
June 6–23	4 2	−435 −468	−446	33	1 35	− 34
July 13–30	5 6	−130 −164	−149	34	69 66	+ 3
Aug. 12–22	4	...	−260	...	48	...
Aug. 26–29	4	...	−308	...	18	...
Sept. 6–13	3 3	−307 −340	−324	33	32 43	− 11
Sept. 14–29	4 3	−395 −475	−429	80	102 45	+ 57
Oct. 6–29	3 3	−152 −207	−180	55	−63 103	−166

Pivot Error

An incidental to each night's observations is a determination of the pivot error. On nights that show abnormal pivot errors, the level errors are under suspicion, and the omission of their observations should reduce any effects due to faulty level corrections.

The ten nights with greatest variations of the apparent pivot error were as follows: 1927 July 8, 19, 21; August 27, 28; September 24; October 6, 16; and 1928 August 29; October 7—and give a mean longitude of $5^h\ 19^m\ 28^s.665$. The groups in Table V that are modified by the omission of these nights are given in their reduced form in Table VI. The effect can be seen most conveniently in fig. 7 (*b*), which is the counterpart of 7 (*a*). with the omission of the nights in question. Fig. 7 (*b*) shows a distinct tidying up as compared with 7 (*a*), which suggests that there is support for the suspicion. It also shows a considerable degree of spread, which suggests that the variations still left in are not particularly connected with levels.

Consider now the effect of omitting these ten sets of observations from Tables II–IV. There will be a loss due to reduction of the amount of data in which cancelling of accidental errors can occur, but a gain if the omitted observations include the ones in which there is most distortion.

TABLE VI

	Level Corrections Grouped by Size				For the Same Groups	
	Number of Observations	Unit $0^s.001$	Mean	Difference	East Longitude in addition to $5^h\ 19^m\ 28^s.6$. Unit $0^s.001$	Difference
1927						
June 13 } July 11 }	5 4	515 450	486	65	55 70	−15
July 12–29 }	4 3	72 25	52	47	54 71	−17
Aug. 23–31 }	3 3	−75 −108	−92	33	62 22	40
Sept. 2–28 }	4 4	−174 −251	−212	77	49 65	−16
Oct. 1–9 }	3 2	−407 −458	−432	51	137 138	−1
Oct. 10–16 }	3 2	−460 −482	−471	22	128 62	66

A reasonable compromise is to give the suspected observations half-weight, and the result of doing so in Table II and fig. 3 is given in fig. 4. The chief abnormality in the former was the middle point for the first period of 1927, which contained two of the suspected observations, and as the result of giving them less weight the point moves downwards (*i.e.* westward) by ·014 sec., and the curve for that period becomes more nearly parallel to its neighbours.

All the points in the second period of 1927 are moved, but by amounts not exceeding ·002 sec., so the result is hardly appreciable, while none of the points in the first period of 1928 are altered at all.

In the second period of 1928 the middle point moves up by ·008 sec., but the curve remains steeper in the section from moderate to strong than in the section from light to moderate.

In both figures 3 and 4 in the more important section, from moderate to strong gradients, the mean value of the increase in longitude is ·09 sec. per millibar per 100 km. in gradient, but the values are more consistent in the second case.

If, instead of giving them half-weight, the suspected observations are dropped entirely, this mean value still holds good. The ray in 1927 (1) would become steeper and that in 1928 (2) less steep. The argument would show no improvement on that in fig. 4, but like it would be a trifle better than in fig. 3.

The effect of giving the observations whose levels are most suspicious half-weights, or omitting them, is thus to make the longitude gradient relationship a trifle more consistent!

In Table III and fig. 5 (*a*) each of the groups used in Table II had been subdivided, and some of the points rest on only two nights' work. It is therefore doubtful if further reduction of data is justifiable. Fig. 5 (*b*) shows the effect of introducing half-weights in these cases. In the case of the last period the ray goes downward instead of upward with increased gradient, but, as explained above, the consistency of fig. 5 (*a*) was rather extraordinary, and that in fig. 5 (*b*) only suffers by comparison, and is certainly sufficient to bring out the greater checking power and consequently more easterly value of the apparent longitude on nights that follow sunny days.

More interest attaches to Table IV, which is the table that provides the strongest direct evidence of the meteorological connection.

A few of the observations used in Tables II, III cannot be used in Table IV owing to their having been made on evenings that followed afternoons on which either no balloon flight was made, or the balloon was lost sight of below half a kilometre. Five of the ten nights' work that it is proposed to omit on level suspicion are of this type. Abnormal pivot errors might arise from faulty readings or from very rapid changes in the true tilt of the pillar. Conditions that were too stormy to admit of pilot balloons being observed to half a kilometre would be just the conditions to give abnormal jumps of the pillar levels within the next few hours (*vide* the paper on the Seismograph Pillar referred to above), and hence there is a real case for regarding the abnormal level

readings as due to this cause rather than to mistakes by the observers, which is a nice little compliment to the observers concerned.

Of the remaining five nights that are challenged one occurred in 1928 August, in which month no comparison was possible owing to uniformity of wind difference. With only four left to consider, it is clearly best not to deal with half-weights, but to omit them entirely in order that an appreciable effect may be introduced. These omissions all occur in 1927, one each in August and September and two in July.

The longitude difference between the groups on wind classification in July was 0·018. Omitting two suspicious nights increases it to 0·038. August was the month with least difference, namely, 0·007. The effect of dropping one observation increases it to 0·018. In September the difference was 0·050, which is one of the largest, and comes down to 0·047, when one night is omitted.

The total effect is therefore slight, and in the direction of making the relationship more consistent, presumably by clearing away a few unrelated causes of error. It definitely contradicts the allegation that the apparent meteorological relationship can be explained away as due to level. That the improvement is only slight is also satisfactory, as this supports the adequacy of the original method of allowing the non-related errors to cancel themselves out.

As the case in favour of a meteorological explanation is strengthened by the elimination of alternative explanations, I examined the possibility of a connection with star magnitude and with shift of pole. Both gave negative results, so numerical results are not included here. The magnitude analysis merely paid a compliment to the travelling micrometer. Effects of the shift of pole should be too gradual to show much over short periods, but, as a matter of fact, the monsoons of 1927 and 1928 were times of but small change, and the effect is negligible compared with the other quantities involved.

Terrestrial Confirmatory Tests

A brief note may be made here regarding terrestrial work on the apparent altitude of the masts at the wireless station. Full results cannot be given, as they would nearly double the length of this paper, and at best are not precise enough to show more than a general trend, but that trend they do show most clearly.

The meteorological work of Colombo Observatory includes the keeping of a continuous record of the temperatures at four levels of one of the wireless masts which is 260 feet high, and whose base is about 7 feet above the level of the observatory compound, and rather more than a mile away.

A telescope (3-inch object-glass) was specially mounted at the observatory so as to observe the summit of this mast. The apparent angle of elevation was observed three times daily for over a year, and varied in the seconds about a mean value of 2° 25′.

After taking the fullest precautions with the instrument, these variations must be attributed to refraction and the actual expansion and flexure of the

mast. The temperature of the unshaded mast is not known exactly, but limits can be fixed both for its effect and that of flexure, which show that these causes will only explain a small portion of the variation.

From the known air temperatures it is possible to calculate the refraction on the assumption that the optical stratification is horizontal (or geocentric). Such refraction corrections, on the whole, improved the agreement, but were far from adequate. They will, however, be altered considerably if it is assumed that the actual conditions are equivalent to a parallel stratification tilted to the horizon, and agreement could be obtained by postulating such a tilt.

The observations showed that the equivalent tilts required to give agreement throughout the year were in opposite directions in the south-west and north-east monsoons, that in the south-west sloping upwards inland, and thus being in accord with the suggestions made in the earlier part of this paper.

A tilt of $1\frac{1}{2}°$ upwards from west to east would account for the observed monsoonal star variations of the order of 0·1 sec. time, if it extended throughout the atmosphere. It is more likely that the effect does not extend throughout, which postulates over $1\frac{1}{2}°$ tilt at the levels concerned.

The mast readings are on a bearing between N.N.E. and N.E., and indicate tilts at certain seasons of over $1\frac{1}{2}°$, probably considerably over. Tilts on a bearing due E., normal to the coast-line, are probably greater still. The mast readings cannot give them explicitly, but do establish a strong case for their passing the required minimum of $1\frac{1}{2}°$ with a good deal to spare.

Another auxiliary experiment may be mentioned in view of the suggestion that is sometimes made to the effect that the Kimura term is largely due to room refraction. There are temple trees near the Observatory which are normally kept well pruned. In 1928 the one south-west of the transit room was allowed to grow till it touched the building and overtopped the roof. It was then cut back to its old state as a small bush. The change, though only a few feet from the instrument, appeared to have no effect.

In conclusion, I should like to thank all the members of the Colombo Observatory staff who have co-operated in the observations on which these suggestions are based.

I also wish to acknowledge my very great indebtedness to Prof. F. J. M. Stratton, P.R.A.S., and to thank him for the numerous occasions on which his advice has been of value to me during my period of service in Ceylon. In particular, it is certain that I should not have persisted in these investigations, in face of various deterrents, if it had not been for his genial encouragement.

OBSERVATIONS OF A DOUBLE NEBULA IN CYGNUS.

W. Milburn.

On 1933 October 14, while observing with the 24-inch reflector of this observatory, I came across a nebulous object of approximately 10·3 visual magnitude at R.A. $21^h\ 29^m\ 8^s{\cdot}5$: decl. $+39°\ 11'{\cdot}5$ (1900), not shown on Argelander's charts. With a high-power eyepiece it appeared to be an elongated nebula with bright centres, estimated to be $4'' \pm$ apart. On the nights of October 16 and 18, and November 8 and 22, the position angle and distance of the nuclei were measured. The combined results are as follows :—

1933·8398	40°·8	3″·47	10·3	10·7	4 nights.

Measures were also made on 5 nights of a companion of approximately 12·0 magnitude which give

1933·8290	139°·4	27″ ±	5 nights.

The object is $3^m{\cdot}8$ preceding, 47′ south of 74 Cygni. As we were unable to identify it in any nebula catalogue, we decided to observe it further and communicate the results to the Society, on the advice of the Astronomer Royal, who kindly informed us that the object was not shown on the Franklin-Ádams plates.

The spectrum was observed on 2 nights by Mr. Espin and myself, and consists apparently of one intensely bright line. A direct-vision spectroscope with 5 prisms before the eyepiece was used.

Wolsingham Observatory, Tow Law :
1933 *December* 6.

NOTE ON MR. MILBURN'S NEBULA.

T. E. Espin.

The Astronomer Royal informs us that Professor Lundmark states : "There is no object included in his Catalogue in the position given, so that Mr. Milburn's object is a hitherto unknown nebula. As it is apparently a double planetary nebula the discovery has special interest, for the known planetaries are not numerous."

Two letters to myself from Professor P. Stroobant, who has had the nebula photographed, are given herewith, and are of special interest.

Observatoire Royal
de Belgique,
Uccle,
1933, *le* 18 *décembre.*

Cher Monsieur,

En réponse à votre lettre du 26 novembre et à votre carte du 15 courant, j'ai l'honneur de vous faire savoir que nous avons examiné la question de l'étoile double que vous nous avez signalée.

Le cliché original de la carte du ciel montre des composantes de même intensité. Il y a une légère nébulosité autour des images qui ont été comparées à l'étoile B située dans le même carré. Mais même sur le cliché les composantes ne sont pas nettement séparées. D'autre part on vient de prendre une plaque de cette région au prisme-objectif (7°) placé sur l'astrographe Zeiss de 30 cm. d'ouverture et de $1^m.50$ de longueur focale. Le spectre est formé de bandes et de raies brillantes ; il sera examiné sous peu au point de vue classification. Sur un cliché pris directement à cet astrographe l'objet parait nébuleux et allongé.

Je vous ferai part des constatations que nous pourrons encore faire, malheureusement notre nouveau télescope de 1^m de diamètre n'est pas encore en fonctionnement.

Veuillez agréer, cher Monsieur, mes salutations très distinguées.

Le Directeur,

P. Stroobant.

Observatoire Royal
de Belgique,
Uccle,
1933, *le* 22 *décembre.*

Cher Monsieur,

Comme complément à ma lettre du 18 courant, je vous communique les renseignements suivants qui sont basés sur les observations de M. le Dr. Bourgeois, assistant à l'Observatoire royal : L'étoile

$$\alpha\ 1900{\cdot}0 : 21^h\ 29^m\ 8^s{\cdot}5 \qquad \delta\ 1900{\cdot}0 : 39^\circ\ 11'{\cdot}5$$

apparaît sur une plaque de 15 m. de pose prise à l'astrographe Zeiss (ouverture 30 cm., longueur focale 150 cm.) comme entourée d'une nébulosité et légèrement elliptique.

Une plaque de 2 heures prise avec le même instrument muni d'un prisme-objectif de 7° d'angle, montre un spectre de raies et de bandes brillantes. On y distingue : 1° les raies de l'Hydrogène de $H\beta$ à $H\epsilon$; 2° les deux raies 4959 et 5007 de *O* III confondues ; 3° la raie 4686 de *He* II bien marquée ; 4° la raie 4363 de *O* III assez faible.

Il résulte d'un examen attentif que cette étoile présente les caractéristiques d'une nébuleuse planétaire qui se situerait dans la classification de Miss Payne (*Handbuch der Astrophysik*, **1**, 66) avant P5, vraisemblablement près de P1.

Veuillez agréer, cher Monsieur, l'expression de mes sentiments distingués.

Le Directeur,

P. Stroobant.

ON THE EVOLUTION OF A ROTATING SYSTEM OF MATERIAL PARTICLES, WITH APPLICATIONS TO SATURN'S RINGS, THE PLANETARY SYSTEM AND THE GALAXY.

Bertil Lindblad, Assoc.R.A.S.

The present considerations start from an elementary theorem which, at least in its precise form, does not seem to have been taken fully into account by cosmologists of the past.

We assume a number of material particles moving in a fixed gravitational field $V(R, z)$ of rotational symmetry and of symmetry around the plane $z=0$. R, θ, z are cylindrical co-ordinates, where z is reckoned along the axis of rotation, R and θ are radius vector and angular co-ordinate in the plane of rotation. We form the quantities (integrals of the undisturbed motion),

$$I_1 = \Pi^2 + \Theta^2 + Z^2 - 2V, \qquad I_2 = R\Theta, \tag{1}$$

where Π, Θ, Z are the velocity-components in the direction of R, θ, z, respectively. For a particle of constant I_2 the quantity I_1 is a minimum for a circular motion around the origin in the plane $z=0$. In fact we have

$$I_1 = \Pi^2 + \frac{1}{R^2} I_2^2 + Z^2 - 2V,$$

and thus

$$\frac{\partial I_1}{\partial \Pi} = 2\Pi, \qquad \frac{\partial I_1}{\partial Z} = 2Z, \qquad \frac{\partial I_1}{\partial z} = -2\frac{\partial V}{\partial z},$$

$$\frac{\partial I_1}{\partial R} = -\frac{2}{R^3} I_2^2 - 2\frac{\partial V}{\partial R} = -2\left(\frac{\Theta^2}{R} + \frac{\partial V}{\partial R}\right).$$

Equating all these derivatives to zero we get

$$\Pi = Z = z = 0,$$

$$\frac{\Theta^2}{R} = -\frac{\partial V}{\partial R}, \qquad \frac{\partial V}{\partial z} = 0, \tag{2}$$

which are obviously satisfied by the circular motion. The second derivatives with respect to Π, Z and z are all positive, and we further have

$$\frac{\partial^2 I_1}{\partial R^2} = -2\left(\frac{\partial^2 V}{\partial R^2} + \frac{3}{R}\frac{\partial V}{\partial R}\right) > 0, \tag{3}$$

if $\left|\frac{\partial V}{\partial R}\right|$ decreases with increasing R more slowly than $\frac{1}{R^3}$, which means that

the circular motion is stable. These results, which are rather self-evident, can be seen at once by forming a diagram with I_2 and I_1 as axes, observing that

$$I_1 + 2V \geqslant \frac{1}{R^2} I_2^2.$$

For the limiting parabola,

$$I_2^2 = R^2(I_1 + 2V),$$

I have proposed the name "characteristic parabola." For one and the same value of V the characteristic parabola has the greatest parameter for the points in the plane of rotation. The two envelope branches of these

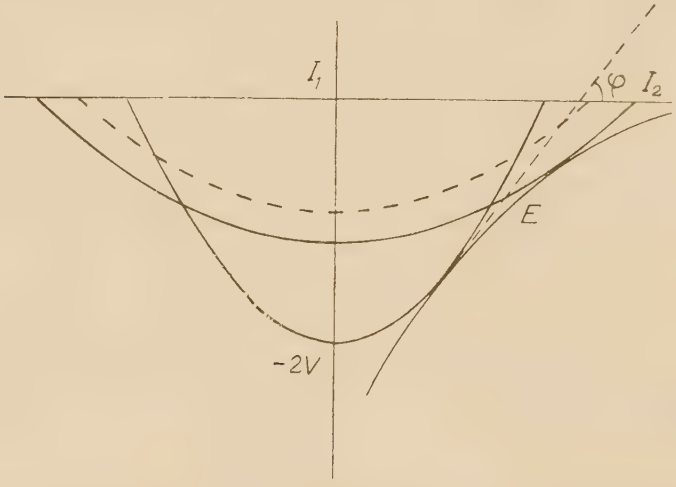


FIG. 1.—*Characteristic diagram for a rotating system. The two full-drawn parabolæ correspond to points in the equatorial plane, the dotted parabola to a point of finite z. E is the envelope, which represents circular motions in the equatorial plane.*

parabolæ, together with the axis $I_1 = 0$, define the region of possible combinations of I_1 and I_2 in the diagram (fig. 1). The inclination ϕ of a tangent common to a characteristic parabola and the envelope is determined by the equation

$$\tan \phi = 2\omega_c, \tag{4}$$

where ω_c is the angular velocity of the motion corresponding to the point of contact. We have further for this point

$$\Pi = Z = 0, \qquad \omega_c^2 R = -\frac{\partial V}{\partial R}, \tag{5}$$

which shows that the point of contact between the characteristic parabola and the envelope corresponds to a circular motion in the plane of symmetry.

In the case when, for $z = 0$,

$$\frac{\partial^2 V}{\partial R^2} + \frac{3}{R}\frac{\partial V}{\partial R} = 0,$$

which corresponds to

$$\frac{\partial V}{\partial R} = -\frac{C}{R^3}, \tag{6}$$

and gives unstable circular motions, the envelope degenerates to a single point on the axis $I_1 = 0$ through which all the characteristic parabolæ pass. This point in the diagram thus represents all the possible circular motions of the degenerated case in question. The fact that this point is situated on the axis $I_1 = 0$ indicates that the circular motions are asymptotic to spiral orbits extending to infinity.

Let us assume now that we have a ring of particles moving in orbits governed by the field $V(R, z)$. We assume further that there will occasionally take place close passages and actual collisions between these particles which, at least in the case of the collisions, will not always be entirely elastic. Choosing the circular orbits for given R with angular velocities ω_c and linear velocities Θ_c as orbits of reference, and denoting with m the mass of a particle, we form

$$\Sigma m(I_1 - 2\omega_c I_2) = \Sigma m(\Pi^2 + \Theta^2 + Z^2 - 2V - 2\Theta_c\Theta) =$$
$$= \Sigma m\{\Pi^2 + (\Theta - \Theta_c)^2 + Z^2 - 2V - \Theta_c^2\}. \tag{7}$$

If the ring of particles is of small depth in R, we can, however, start from one of these circular orbits with angular velocity $\omega_c^{(0)}$, linear velocity $\Theta_c^{(0)}$ and radius R_0, denoting by Δ the difference from this orbit, and develop as follows :—

$$\Delta I_1 = \tfrac{1}{2}\left(\frac{\partial^2 I_1}{\partial \Pi^2}\right)_0 (\Delta\Pi)^2 + \left(\frac{\partial I_1}{\partial \Theta}\right)_0 \Delta\Theta + \tfrac{1}{2}\left(\frac{\partial^2 I_1}{\partial \Theta^2}\right)_0 (\Delta\Theta)^2 + \tfrac{1}{2}\left(\frac{\partial^2 I_1}{\partial Z^2}\right)_0 (\Delta Z)^2 +$$
$$+ \left(\frac{\partial I_1}{\partial R}\right)_0 \Delta R + \tfrac{1}{2}\left(\frac{\partial^2 I_1}{\partial R^2}\right)_0 (\Delta R)^2 + \tfrac{1}{2}\left(\frac{\partial^2 I_1}{\partial z^2}\right)_0 (\Delta z)^2,$$

omitting the derivatives which are obviously zero. We have further

$$\Delta I_2 = \Theta_c^{(0)}\Delta R + R_0\Delta\Theta + \Delta\Theta\Delta R,$$

$$\omega_c = \omega_c^{(0)} + \frac{\partial \omega_c}{\partial R}\Delta R.$$

ω_c is defined for an arbitrary (R, z) as a function of R only. After some reduction, we get

$$\Sigma m(\Delta I_1 - 2\omega_c \Delta I_2) = \Sigma m[\Pi^2 + (\Theta - \Theta_c)^2 + Z^2 + A'(\Delta R)^2 + Bz^2], \tag{8}$$

where

$$A' = \frac{A(4\omega_c^{(0)2} - A)}{4\omega_c^{(0)2}}, \qquad A = -\left(\frac{\partial^2 V}{\partial R^2}\right)_0 - \frac{3}{R}\left(\frac{\partial V}{\partial R}\right)_0, \qquad B = -\left(\frac{\partial^2 V}{\partial z^2}\right)_0 > 0. \tag{9}$$

It can easily be verified that

$$A' > 0 \quad \text{for} \quad -1 < n < +3, \tag{10}$$

if we assume, for $z = 0$,

$$\frac{\partial V}{\partial R} = -\frac{C}{R^n}.$$

For each point (R, z) we have now for a departure from the original state due to collisions and passages

$$\Sigma m dI_2 = 0 \tag{11}$$

and, assuming the collisions to be partly inelastic,

$$\Sigma m dI_1 < 0. \tag{12}$$

For the particles which meet at a certain point at a certain moment the left-hand member of equation (8) will therefore decrease in consequence of the collisions, which means that the velocity dispersion of these particles will tend to decrease.

We consider now the full orbital motions of the particles in question. A decrease of the velocity dispersion will mean that in the average over a sufficiently long time the particles will be distributed in ω_c in a different way than in the case of a corresponding average taken with the original dispersion, and we must take this fact into account in the left-hand member of (8). We can suppose the field of force to be such that $A' > 0$, which means that ω_c will decrease with increasing R. Let $\overline{d\omega_c}$ be the average change of ω_c for the particles of a certain value of I_2. Now the average angular velocity for the circular motions at the successive points visited by a particle in its orbit will be approximately equal to the angular velocity of the circular motion corresponding to the value of I_2 of the particle. Therefore we can put

$$\overline{d\omega_c} = \frac{d\omega_c}{dI_2} dI_2,$$

$$\Sigma m \overline{d\omega_c} = \Sigma m \frac{d\omega_c}{dI_2} dI_2 = 0,$$

to the order of magnitude considered, because $\Sigma m dI_2 = 0$. We can further consider with sufficient approximation positive and negative values of $\overline{d\omega_c}$ equally probable for all values of ΔI_2 and have thus

$$\Sigma m \overline{d\omega_c} \Delta I_2 = 0. \tag{13}$$

We may, however, proceed more rigorously in the following way. We define $\bar{\omega}_c$ as the mean of ω_c for a given ΔI_2 in the original motion of the group of particles considered. Then we can put

$$\bar{\omega}_c = \omega_c^{(0)} + \frac{d\omega_c}{dI_2} \Delta I_2,$$

and get, because

$$\Sigma m \omega_c^{(0)} dI_2 = 0,$$

$$d\Sigma m(\Delta I_1 - 2\omega_c \Delta I_2) = \Sigma m[dI_1 - 2(\bar{\omega}_c + \overline{d\omega_c})(\Delta I_2 + dI_2) - 2\bar{\omega}_c \Delta I_2] =$$

$$= \Sigma m\left[dI_1 - 2\frac{d\omega_c}{dI_2}(2\Delta I_2 dI_2 + (dI_2)^2)\right] = \Sigma m\left[dI_1 - 2\frac{d\omega_c}{dI_2} d(\Delta I_2)^2\right].$$

We assume in the present case $\dfrac{d\omega_c}{dI_2} < 0$. The quantity $\Sigma m d(\Delta I_2)^2$ is equal to

$R^2\Sigma m d\Theta^2$ at the point of the encounters and is very small,* as long as there is no pronounced correlation between ΔI_2 and dI_2. We can assume here that in general $\Sigma m\Theta^2$ decreases with $\Sigma m I_1$, in consequence of the inelastic encounters. We have, therefore,

$$d\Sigma m(\Delta I_1 - 2\omega_c \Delta I_2) < 0, \qquad (14)$$

where we can now extend the sum to all particles of the ring originally considered.

In the general mixed motion of all the particles the left-hand member of equation (8) will thus decrease, as long as collisions still occur, *i.e.* as long as any Π, Z, $\Theta - \Theta_c$ and z differ from zero. The quantities

$$\Sigma m\Pi^2, \qquad \Sigma m(\Theta - \Theta_c)^2, \qquad \Sigma m Z^2, \qquad \Sigma m z^2$$

in the right-hand member will thus decrease continuously, giving in the limit

$$\Pi = Z = \Theta - \Theta_c = z = 0,$$

whereas $\Sigma(\Delta R)^2$ will ordinarily approach to a finite limit. The ultimate result will thus be that the particles all describe circular orbits in the plane of rotation, forming together a flat ring. This process of evolution is easy to follow in the diagram of fig. 1, in which the particles ultimately get packed towards the envelope E.

The existence of the ring of course presupposes that it is stable with respect to the perturbations due to irregularities in the distribution of the particles in the ring. In this case we can associate the perturbating forces in question with the "passage" forces.

The two limiting cases in (10), for which A' changes its sign, are of course of very different nature. The latter case, $n = +3$, corresponds to unstable circular motions and needs no further comments. For $n < -1$ the envelope curve in the characteristic diagram turns its concave side towards the origin. We may assume a distribution in the characteristic diagram such that for a series of arbitrary chosen characteristic parabolæ corresponding to different values of R we get approximately velocity-distributions of spherical symmetry around $\Theta = \Theta_c$, $\Pi = Z = 0$, as centres. These velocity-distributions will then be represented in the diagram by a series of equidensity lines in the form of straight lines (chords of the parabolæ) of equations $I_1 - 2\omega_c I_2 = \text{const.}$, which are parallel to the tangent in common for parabola and envelope. We now draw in addition a series of chords in such a way that $\Delta I_1 - 2\omega_c \Delta I_2$ is the same for the parabolæ in question. For $A' < 0$ the series of chords drawn in this way will, according to (8), correspond to an increasing dispersion in Π, $\Theta - \Theta_c$, Z, when we proceed in either direction from the parabola valid for the radius R_0, and will therefore not converge towards the envelope E in the diagram. It will therefore be possible even with a continuously decreasing value of the sum $\Sigma m(\Delta I_1 - 2\omega_c \Delta I_2)$ to have a considerable net stream of particles flowing in

* In the case of elastic encounters, *e.g.* in a ring of gas, this term would in general be slightly positive, causing a slow stratification of the gas parallel to the plane of rotation (the interstellar gas of the Galaxy may offer an example of such a process).

the direction from the regions of R_0 towards the far interior of the system, as well as outwards with I_1 increasing over the velocity limit $I_1 = 0$. In the case $n > -1$ ($A' > 0$) a similar series of chords of constant $\Delta I_1 - 2\omega_c \Delta I_2$ will converge towards the envelope for R smaller as well as bigger than R_0. It is clear that the case $n < -1$ is therefore less favourable for the development of a dense ring of matter moving in circular orbits than the physically more normal case $n > -1$.

Saturn's Rings.—The application of the theorem just developed to the case of Saturn's rings lies of course very near at hand. We can understand immediately the formation of the flat rings from a wider distribution of small satellites as a consequence of a long series of slight inelastic collisions between these satellites.

Planetary System.—We assume that an original distribution of small particles around a primitive sun has a considerable depth in R. Outside of Roche's limit the particles of low internal velocity dispersion will have a strong tendency to condense into particles of larger size, the primitive planets, which will grow continuously by the further amalgamation with smaller particles. The particles of larger size formed in this way at different distances from the centre will possess small orbital inclinations and eccentricities. On the whole those smaller particles which escape being destroyed by violent encounters with one another will have a tendency by their decreasing velocity-dispersion, in consequence of the theorem given above, to associate with the big ones, forming systems which are in several ways, though on a smaller scale, analogous to the big system originally considered. These satellite systems will ordinarily get the same direction of rotation as the original system, corresponding to the angular momentum of the matter which lies within a certain distance and within a certain limit in relative velocity reckoned from the primitive planet.

It is possible that the planets, and the remaining small particles which have not been volatilized by violent encounters, form only a small fraction * of the mass of the original meteoric cloud surrounding the sun. The particles most likely to escape annihilation are those of nearly circular velocities, and it does not seem impossible to assume that the process of volatilization and the formation of planets and satellite systems go on parallel to one another.

In this way it seems possible to revive an old hypothesis regarding the formation of the solar system. Whether this hypothesis is probable from other reasons will not be considered here.

Galactic System.—I have shown in a recent paper † that in this case already the internal disturbances due to the formation of accidental agglomerations ("local systems") will cause that the frequency function of the velocities at a point in the galactic plane will have its maximum near the envelope in the characteristic diagram, *i.e.* near the circular orbits in the galactic plane. The frequency must decrease from here towards the limit

* *Cf.* H. Jeffreys, *The Earth*, p. 250 (1924).

† *Arkiv för Matematik, Astronomi och Fysik* 23A, No. 18; *Stockholm Meddelande* No. 11 (1933).

$I_1 = 0$, and this fact explains in a general way the phenomenon of the observed asymmetrical drift of large stellar velocities.* This shows, on the other hand, that the velocity limit $I_1 = 0$ unquestionably plays an important part for the constitution of the system. It is, in fact, necessary to assume that the system is steadily losing particles which approach slowly, as a consequence of an accumulation of slight perturbations of their motions, to the velocity limit in question. It is further conceivable that in earlier stages of the system particles were expelled at a much more rapid rate than at present. In *Stockholm Medd.*, No. 11, I have shown that this process will cause a general increase of concentration of the remaining matter towards the galactic plane, and it may be worth while to consider the arguments more fully in this connection. The quantities I_1 and I_2 are considered as variables, which only in a steady state become integrals of the motion. Before a steady state has been attained, we shall have to count with slightly different characteristic diagrams for different vertical half-sections of the system defined by the angular co-ordinate θ. By the virial theorem, if $\bar{T}$ is the kinetic energy of the system reckoned per unit mass, $\bar{W}$ the exhaustion of potential energy reckoned in the same way, we have for a steady, or quasi-steady, state

$$2\bar{T} - \bar{W} = 0. \tag{15}$$

We have further

$$\bar{W} = \tfrac{1}{2}\overline{mV}, \qquad \tfrac{1}{2}I_1 = T - V, \tag{16}$$

and therefore

$$\left.\begin{aligned} \bar{T} = -\tfrac{1}{6}\overline{mI}_1, \qquad \bar{W} = -\tfrac{1}{3}\overline{mI}_1, \\ \bar{T} - \bar{W} = +\tfrac{1}{6}\overline{mI}_1, \end{aligned}\right\} \tag{17}$$

all means indicated being reckoned per unit of mass. Assume now that a fraction f of the original mass is expelled in the form of particles with $I_1 = 0$. The total energy expelled is thus $f.I_1 = 0$. The total energy, which is unchanged, has thus in the new state to be divided by $1 - f$, in order to give the energy per unit mass. We thus have, if an accent denotes the new state,

$$(\bar{T} - \bar{W})' = \frac{\bar{T} - \bar{W}}{1 - f}. \tag{18}$$

The energy per unit mass thus decreases (increases numerically) approximately with the fraction f.

When the system has rearranged itself in a steady, or quasi-steady, state with

$$\frac{1}{2}\frac{d^2\mathfrak{J}'}{dt^2} = M'(2\bar{T} - \bar{W})' = 0,$$

where $\mathfrak{J}'$ is the moment of inertia about the origin, $M' = M(1 - f)$ the mass of the system, we must have, according to (17) and (18) $(\overline{mI}_1)' = \dfrac{\overline{mI}_1}{1 - f}$. (As the expelled matter enters in the original ΣmI_1 with the contribution zero,

* *Cf.* "Die Milchstrasse," *Handbuch der Astrophysik V/2* (1933).

we may remark that, if we consider in both cases the matter remaining after the expulsion only, $\overline{mI_1}$ is unchanged.) By (17) $\bar{W}$ must increase and we should have

$$(\bar{W})' = \frac{\bar{W}}{1-f}. \tag{19}$$

The departure of the particles with the mean potential $\bar{V}$, if the system is in other respects unchanged, would give a total potential $\frac{\bar{W}-f\bar{V}}{1-f}$, which is obviously smaller. It is necessary, therefore, that the remaining matter gets closer packed together, in order to give the net increase of $\bar{W}$ demanded.

The cause of this contraction from the direct dynamical point of view is, in the case of a flattened, rotating system, the decrease of the potential V in the outer regions of the system, on account of the departure of the particles with $I_1 = 0$. This will cause an increase of the force along R, *i.e.* of the numerical value of $\frac{\partial V}{\partial R}$, in the outer regions, and a contraction will therefore follow, whereby an average increase of V for the remaining particles of the system occurs. The contraction is thus a phenomenon affecting primarily the outer regions of the system. The resulting increase of potential, ΔV, will, however, in a certain region increase very rapidly from the outer regions towards the interior, where ΔV becomes again more uniform. Very far out the original decrease of V for given (R, z) will not be compensated, so that $\Delta V < 0$, approaching for still larger R and z asymptotically to 0.

We can understand from this that the envelope E in the characteristic diagram will as a whole proceed steeper after the contraction, and that the new envelope will intersect the old one at some point (fig. 2). The same conclusions can be drawn in the following way. The circular motions of constant I_2 will after the contraction occur at points of smaller R, whereby ω_c will increase for given I_2. As by (4) ω_c measures the inclination of the envelope, it is evident that the envelope has obtained a steeper run. In the interior, where ΔV is large and ΔR small for the motions in question, the points representing the circular motions in the diagram will sink, and in the outer regions, where ΔV is small and ΔR large, the representative points will rise.

Consider now a star of the same I_2 as a certain circular motion but of greater I_1. This star will oscillate around the circular motion, visiting points of larger, as well as smaller R. In the outer regions, just where ΔV begins to increase very rapidly inwards, this star is likely to acquire a smaller net increase of I_1 in consequence of the contraction than a star moving in the circular orbit. The representative points in the diagram will then come closer together. Particles which differ from the circular motions in these regions of the system will thus approach towards the envelope in the diagram. This means that the particles will get closer packed towards the galactic plane with smaller dispersion in the relative velocities. The closer packing

in space is a consequence of the smaller velocity dispersion, as well as of the bigger forces $\left|\frac{\partial V}{\partial R}\right|$ and $\left|\frac{\partial V}{\partial z}\right|$.

The equations above demand, however, an increase of the mean kinetic energy $\bar{T}$. A contribution to this effect is given in the outer regions by an increase of the rotational velocities due to the decrease of R. In the interior, where the circular motions are likely to get a bigger decrease of I_1 than other

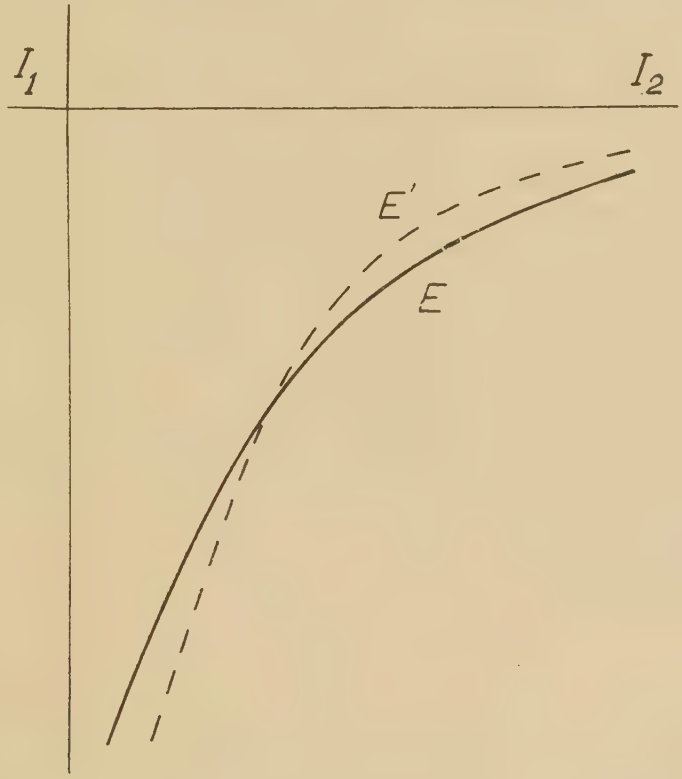


FIG. 2.

motions of the same I_2, there will be an increase of the internal dispersion of the velocities.

Even if the rate at which the particles are expelled from the system is small in the present state of our Galaxy, it seems well possible that it may have been of a considerable order of magnitude in earlier stages of evolution, and there is little doubt that the phenomenon of the Milky Way, the packing of matter towards the galactic plane with small internal dispersion of velocity, is to a considerable extent a product of such a process. As mentioned above, we have in the phenomenon of the asymmetrical drift of big stellar velocities an indication that the process is still at work. It is clear, however, that other processes as well, which cause a dissipation of the kinetic energy of the stars, such as collisions between stars, or between stars and meteoric or gaseous matter, etc., will give contributions to the same end.

That the meteoric matter will tend to concentrate towards the galactic plane is obvious from our previous discussion.

It is well conceivable that the increasing flattening of the system in its outer regions will lead to a dynamically unstable state, and that we have to count with a possible "ordinary" instability, when the flattening of the outer regions has proceeded very far. The system may then break up rather suddenly, and massive arms like those of the spiral nebula M51 may be expected to appear.

At an earlier state in the evolution of the system there is likely to occur a development of a spiral structure at the border of the system, where the rate of change of the central force with the distance is likely to proceed with steep gradients, leading to an appearance of asymptotic spiral orbits. A development of asymptotic spiral orbits in consequence of a growing instability of the circular motions in the outer regions of the system may be thought to proceed from the border rather deeply into the system, and may lead to complicated spiral structures, if a slight tidal force from the outside is added. The asymptotic spirals at the border of a flattened spheroidal body are known to correspond well to the spiral arms of nebulæ like M33 and M81, but is perhaps not out of the question that more complicated structures may be explained in an analogous way.

A general order of evolution can probably be traced from a widespread, irregular type of high angular momentum (perhaps a Magellanic cloud type), over spirals like M33, M81 and M51, to elliptical nebulæ, which have only left a faint ring-shaped edge in the equatorial plane of rotation.

Stockholm Observatory,
Saltsjöbaden :
1933 *December.*

ON PERIODIC OR SECULAR CHANGES OF VELOCITY ON JUPITER. II. THE GREAT EQUATORIAL CURRENT.

A. Stanley Williams.

A preliminary paper on this subject, published in the *Monthly Notices* (**93**, 409, 1933), dealt with the observed changes of velocity of the North Tropical Current. It is now proposed to consider in a similar manner the changes of velocity that have been observed in the great Equatorial Current of Jupiter. But first it should be premised that the present work was not undertaken with the expectation of finding definite periodicities in the velocities of the surface currents of the planet, because the time-interval is still far too short to expect much success. But the chief object is to bring together and put on record in a concise, convenient and continuous manner the various reliable determinations of the rotation period of the principal currents that have been made during the last half-century, and it is hoped

that the material so collected may ultimately serve as the foundation for future and more successful investigations. The bare material at the present time is scattered in many different publications, and is, moreover, of very unequal value. It is desirable, and indeed really necessary, that this work should be done by someone personally conversant with it, both as an observer and computer. This must be the excuse for the writer undertaking the task.

The great Equatorial Current of Jupiter is too well known to require much description. It may be said to cover or include the whole surface of the planet from about latitude 10° N. to latitude 16° S., though the actual limits vary slightly in latitude from time to time. Normally the current may be said to include the southern half of the N. Equatorial belt (usually double) and the northern half of the S. Equatorial belt (also usually double), with the whole of the bright intermediate zone—the Equatorial Zone. Very commonly there is a faint dark belt nearly in the middle of this bright zone and approximately marking the planet's equator. The whole current may be said to have usually a more or less equable motion throughout its whole width, but this is not always the case, and it sometimes happens that the velocity of the half north of the equator may differ quite considerably from that of the half south of the equator. It is therefore necessary to treat the northern and southern halves of the great current as though they formed two distinct currents, though the two actually only form parts of the same great Equatorial Current. The half south of the equator is here designated the S. Equatorial Current, and the half north of that line the N. Equatorial Current.

Table I. gives the observed rotation period of the S. Equatorial Current in the various years or oppositions of the planet. It corresponds to Table I. of the paper relating to the N. Tropical Current, and the weights in the third column have the same significance.* The accidental error of a determination of weight 3 is not likely to exceed one second of time, and larger differences are pretty certainly due to real changes. The results with weight 3 are thoroughly to be relied on. Those with weight 2 are also pretty reliable, and are not likely to be more than 3 or 4 seconds in error. But those with weight 1 are only to be regarded as approximate, since they are often only derived from single spots, or from several spots that may have been badly observed, or only for short periods of time, or confined to a restricted region of the planet in longitude.

Most of the determinations subsequent to 1906 have been derived from the various *Memoirs* of the Jupiter Section of the British Astronomical Association. The earlier ones are from the table on page 100 of the writer's *Zenographical Fragments*,† or from the lists in two papers published in the *Monthly Notices*.‡ For 1880, 1, the value given in *M.N.* (**72**, 155, 1910) has been substituted for the original figure. Between 1891 and 1897 no observations could be found, and in order to lessen the gap the writer has reduced some of his observations of the equatorial spots made in 1892, 3.

* See *M.N.*, **93**, 412, 1933.
† *Zenographical Fragments*, **2**, 100 (London), 1909.
‡ *M.N.*, **56**, 147, 1896, and **58**, 14, 1897.

The value for this year ($25^{s}\cdot3$) is derived from 28 well-observed spots. It is gratifying to note that we have a nearly continuous record of the rotation period (or velocity) of the S. Equatorial Current from 1879 to 1928, a period of 49 years. There are still a few regrettable gaps. It is hoped that it may be possible to fill these up eventually, and that better values may be derived for some of the results having only low weights.

TABLE I

Observed Rotation Period of S. Equatorial Current

Year	Rotation Period	Wt.	Year	Rotation Period.	Wt.
	h m s			h m s	
1879	9 49 59·0	1	1906, 7	9 50 28·3	3
1880, 1	9 50 7·6	2	1907, 8	32·5	3
1881, 2	9·3	1	1908, 9	26·5	3
1882, 3	9·7	1	1909, 10	27·4	3
1883, 4	12·4	1	1911	32·5	2
1884, 5	12·3	1	1912	...	...
1885	14·3	1	1913	11·6	1
1886	22·9	1	1914	17·6	1
1887	22·4	3	1915	28·7	1
1888	27·8	3	1916, 17	26·8	1
1889	30·3	3	1917, 18	61·4	1
1890	28·0	3	1918, 19	46·8	1
1891	26·4	1	1919, 20	60·3	1
1892, 3	25·3	3	1920, 21	49·4	1
1897	34·6	3	1922	74·9	1
1898	24·0	3	1923	48·1	1
1899	24·5	3	1924	...	...
1900	23·0	3	1925	26·6	1
1901	30·0	3	1926	...	...
1902, 3	26·3	3	1927, 8	19·2	1
1903, 4	26·0	3			
1904, 5	29·4	3	1916	36·1*	3
1905, 6	31·4	3	1924	43·6*	3

* Mean of 7 years.

Better values are particularly wanted for the years following 1911. The inferior quality of the data available for these years is partly the result of war-time conditions, and partly owing to the absence of conspicuous spots, but it would seem also to indicate a regrettable apathy on the part of observers in general. It will be noticed that from 1913 onwards no value has been given a higher weight than 1. As this seemed surprising, a careful revision was made of the published observations, but it resulted in no change. Most of the published annual results are based on the observations of one or two spots only, or if more than one or two, the spots were close together in longitude. Also in some cases the spots were only observed for comparatively short intervals of time, or the observations were only few in number. Sometimes, moreover, there were uncertainties as to correct identification. It will be noticed that the results for the years following 1911 are widely discordant *inter se*. Under the circumstances it seemed

that the best way of dealing with these discordant results was to form them into two groups, as under :

Mean date 1916. Rot. Per. $9^h\ 50^m\ 36^s.1$. Wt. 3.
„ 1924. „ $9^h\ 50^m\ 43^s.6$. „ 3.

The first result is the mean from 14 spots, the second from 15 spots. That this is the proper way of treatment is indicated by the agreement of these mean results with the earlier observations. In place of wide discordances we get nearly perfect agreement.

The observations contained in Table I. are shown in diagram form in fig. 1, from which it will be noticed that there has been a general and nearly continuous increase in the length of the rotation period throughout the

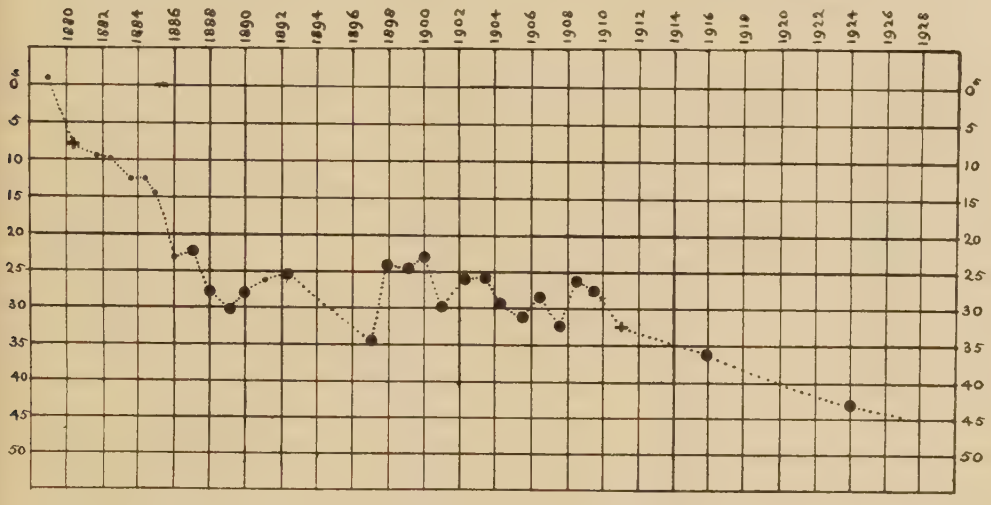


FIG. 1.—*Velocity Curve of South Equatorial Current.*

Vertical Scale, $60^s = 72$ *km./h.* ● =*weight* 3, + =*weight* 2, • =*weight* 1.

49 years covered by the observations except for some minor fluctuations. Between 1879 and 1928 the rotation period increased from $9^h\ 49^m\ 59^s$ to $9^h\ 50^m\ 45^s$, a difference of no less than 46^s, equivalent to a *decrease* in the velocity of the current of 55 km./hour.

Another remarkable thing is the entire absence of indications of any definite long-period periodicity. And in particular there is nothing resembling either the 11-year sunspot periodicity or the 12-year period of the planet's revolution round the sun. This came as a surprise, since it is in this great Equatorial Current that one would have expected to find indications of a long-period periodicity.

But if there are no signs of a periodicity of long period, the observations do strongly suggest the existence of one of short period. The regular succession of maxima and minima between the years 1897 and 1911 seems too remarkable to be fortuitous, and a periodicity having a period of about $2\frac{1}{2}$ years and an amplitude or range of about 9 km./hour in velocity is strongly suggested.

The future history of the S. Equatorial Current should be an interesting one, and it seems somewhat conjectural. The present observations stop with the opposition of 1927, 8, but it was in the following year that occurred the wonderful convulsions which have been so graphically described recently by Messrs. Hargreaves, Peek and Phillips.* In these convulsions the whole southern half of the Equatorial Current became more or less involved, as far north as the equator. Consequently it is impossible to say what was the real rotation period of the S. Equatorial Current during that opposition, and no determinations appear to have been made or published since.

Table II. contains the observations of rotation period of the N. Equatorial Current between 1884 and 1929, and fig. 2 shows them in diagram form.

TABLE II

Observed Rotation Period of N. Equatorial Current

Year	Rotation Period	Wt.	Year	Rotation Period.	Wt.
	h m s			h m s	
1884, 5	9 50 9·2	1	1909, 10	9 50 31·2	3
1887	40·1	2	1911	32·5	2
1888	23·9	3	1912	...	...
1889	30·3	3	1913	12·1	3
1890	28·0	3	1914	17·2	3
1891	31·6	1	1915	14·8	3
1892, 3	25·3*	3	1916, 17	14·2	3
1897	36·0	1	1917, 18	19·4	3
1898	26·4	2	1918, 19	19·4	3
1899	28·2	1	1919, 20	17·0	2
1900	27·1	3	1920, 1	34·3	2
1901	25·3	3	1922	26·4	3
1902, 3	36·0	1	1923	9·7	2
1904, 5	28·6	3	1924	12·9	2
1905, 6	30·0	3	1925	21·3	2
1906, 7	36·7	3	1926	23·2	3
1907, 8	34·1	3	1927, 8	24·4	3
1908, 9	27·3	3	1928, 9	21·1 †	2

* Mean of 19 well-observed spots.

† Mean of 6 spots well observed, but confined in longitude between 222° and 372° (System I).

It will be noticed that the curve of this current corresponds closely with that of the S. Equatorial Current from 1884 to 1911, when a sudden jump of no less than 20^s occurs in it. This is followed by considerable fluctuations, but on the whole there is a tendency towards the increasing length of the period. The two curves differ, however, somewhat widely after 1911. It should be noted that the later observations of the N. Equatorial Current are nearly all good, mostly with weight 3, so that these changes are certainly real.

There is again no indication of any definite periodicity of long period. But the observations do again strongly suggest the presence of the short-

* *M.N.*, **89**, 209, 1928.

period periodicity of about $2\frac{1}{2}$ years. In fact this is even more marked than it was in the case of the S. Equatorial Current, and, moreover, this periodicity of about $2\frac{1}{2}$ years is distinctly traceable after 1911, notwithstanding the large fluctuations then occurring. It is also traceable between the years 1888 and 1892, 3. With only annual observations of velocity available, it may be difficult to disentangle such a short periodicity as $2\frac{1}{2}$ years from the other fluctuations. But the observations are so definite that the existence of the periodicity would seem to be certain.

It is gratifying to be able to record the fact that nearly all the thousands of transit observations of spots, from which the results embodied in the

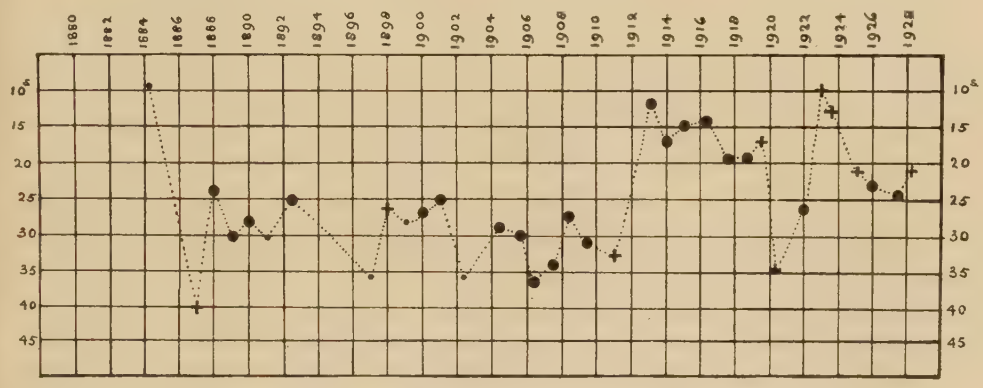


FIG. 2.—*Velocity Curve of North Equatorial Current.*

Vertical Scale, $60^s = 72$ *km./h.* ● =*weight* 3, + =*weight* 2, • =*weight* 1.

tables were chiefly derived,* were made by British observers, mostly amateurs working from pure love of the subject.† Previously to 1879 there appear to be no observations of rotation period suitable for comparison. The early observations of Cassini, Schroeter, Herschel and Schmidt, however interesting they may be from the historical point of view, are of no use. Cassini was certainly the first to observe the rapid motion of the spots near the equator, and it is evident, moreover, that he had recognised the important fact of the existence of a great equatorial current.

Summary

(1) The systematic observations of the last half-century give no indication of any long-period periodicity in the velocity of the Equatorial Current of Jupiter.

(2) But they do indicate the existence of a short-period periodicity of about $2\frac{1}{2}$ years, having an amplitude or range of about 9 km./hour in velocity.

* Results based on micrometric measures have been included when available, but these are few in number.

† The activity shown by some of the observers is amazing. In the course of a single opposition of Jupiter the late Major Molesworth alone observed more than 8000 transits of spots on the planet.

(3) Between 1879 and 1928 the rotation period of the S. Equatorial Current increased in length from $9^h\ 49^m\ 59^s$ to $9^h\ 50^m\ 45^s$, a difference of 46^s, meaning a *decrease* of 55 km./hour in the velocity of the current.

(4) The changes in the motion of the N. Equatorial Current have been more irregular, and sometimes differ considerably from those of the S. Equatorial Current.

Polvarth, St. Mawes :
1933 *December* 14.

OBSERVATIONS OF SS AURIGÆ (060547).

(Third Series.)

P. M. Ryves.

This communication, which is a continuation of that published five years ago (*M.N.*, **88**, 607), contains 740 observations of SS Aurigæ made at Zaragoza on 694 nights during the period 1928–1932.

The methods of observation and presentation of the results are the same as before, except that signs have been introduced in order to make it possible to distinguish between an estimate made with the comparison star to the right of the variable and one made with the comparison star to the left, thus permitting the application of corrections for personal equation of position. The neutral position means that the comparisons were made by the successive method, or that the star was observed in both positions, or that the indication is lacking in the notes.

In deducing the magnitudes here published no corrections have been applied ; in most cases, however, the effect will probably be small as the observations are made in such a way that the errors tend to neutralise one another and cancel out.

When the observations are used for the purpose of deducing a light-scale the corrections must be taken into account.

The position signs are not given in the case of observations made in the year 1928 and the first half of 1929, as personal equation was uncertain and generally small at that time.

A correction of about $+0^m.2$ might be applied to the first observation made after a rapid increase in brightness, as there is evidence of overshooting effect in such cases. The second observation may also be somewhat affected.

As before, the designations of the comparison stars are those of Harvard, and the magnitudes are from the McCormick revision, except *r*, which is taken as 12·30, and is probably still brighter. Star *k* has shown residuals suggestive of variability on a few occasions.

The value of the grade remains $0^m.05$.

Explanation of Symbols and Abbreviations

W = weight, 1 to 5.
Sk = sky conditions about the variable.
! = clear transparent sky.
: = clear but less transparent
; = some haze or mist.
. = star low, sky clear unless otherwise indicated.
j = unsteady (jumpy).
i = interference from clouds.
(= moonlight.
t = twilight.
? = doubtful observation.

* = 9-inch reflector.
¶ = 8-inch refractor.
§ = 18-inch reflector.
Weight number in italics = 3-inch refractor.
Comparison in brackets (*g*4), half or $\frac{2}{3}$ weight.
Comparison star in brackets (*t*) indicates that such star was glimpsed.
g′ = comparison star *g* observed in left-hand position.
g = comparison star *g* observed in right-hand position.
g° = neutral position, no correction to be applied.

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1928 Jan.					
14	5260·55	*u*oN	<13·8	3	!
15	5261·57	*t*oN	<13·2	3	!
16	5262·53	*t*4N	<13·4	3	!
17	5263·51	*t*8N, 2*u*N	<13·7	3	!
18	5264·52	*t*oN	<13·2	3	!
19	5265·31	*s*oN	<13·0	3	!j
20	5266·57	*t*6N	<13·5	3	!
21	5267·28	*r*oN	<12·3	3	;i
22	5268·35	*t*oN	<13·2	3	!
23	5269·29	*t*6N (*w*)	<13·5	3	!
23	5269·63	*s*4N	<13·2	3	!
25	5271·29	*t*2N	<13·3	3	!
26	5272·27	*r*oN	<12·3	3	:
27	5273·55	*t*oN	<13·2	3	!
28	5274·47	*t*oN	<13·2	3	!
30	5276·60	*s*oN	<13·0	3	!
31	5277·59	2*r*N	<12·2	3	(:
Feb.					
3	5280·58	*n*oN	<11·5	3	(!
5	5282·31	*p*oN	<11·8	3	(:
6	5283·54	*p*6N	<12·1	3	(!
7	5284·29	*r*6N, *q*oN	<12·5	3	!
8	5285·34	*q*4N	<12·6	3	!
9	5286·32	*t*oN	<13·2	3	!
10	5287·43	*t*oN	<13·2	3	:
11	5288·46	*u*oN	<13·8	3	!
12	5239·30	*q*oN	<12·5	3	!
13	5290·29	*q*oN	<12·5	3	!
13	5290·59	*t*2N	<13·3	3	!
14	5291·31	*q*oN	<12·5	3	:
15	5292·30	*s*oN	<13·0	3	!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1928 Feb.					
15	5292·57	*t*oN	<13·2	3	!
16	5293·33	(*r*12, *q*10), 2*t*	13·00	2	!
16	5293·52	(*r*10, *q*4), (5*s*)	12·75	2	!
17	5294·32	*p*3, 8*r*	11·92	2	:
17	5294·55	*p*2, 4*r*, (*o*9, 10*q*)	11·98	3	!
18	5295·30	*l*10, *m*6, *o*2, 1*n*	11·52	3	!
18	5295·62	*m*5, *o*3, 1*n*	11·52	3	!
19	5296·30	*l*2, =*m*	11·15	2	!
19	5296·60	*g*7, *k*6, *l*1, =*m*	11·12	3	:
20	5297·30	*g*4, 2*k*	10·85	3	!
20	5297·60	*g*3, *k*2, 1*l*, (8*m*)	10·90	4	!
21	5298·40	*f*4, 1*g*, 2*k*	10·72	3	!
21	5298·58	*f*3, 3*g*, 2*k*, 6*l*	10·68	4	:
22	5299·30	*f*3, *g*1, 3*k*, 2*l*	10·77	2	!
22	5299·55	*f*2, =g, 4*k*, 6*l*	10·68	4	;
Mar.					
21	5327·30	*q*2N	<12·5	3	!
24	5330·42	*n*2N	<11·5	3	!
26	5332·46	*r*2N	<12·4	3	:
28	5334·46	*r*oN	<12·3	3	(:
29	5335·32	2*r*N	<12·2	4	(:
31	5337·30	*p*oN	<11·8	3	(!
Apr.					
1	5338·37	2*p*N	<11·7	3	(!
3	5340·46	*p*4N	<12·0	3	(!
4	5341·35	*p*2N	<11·9	3	(!
8	5345·34	*s*oN	<13·0	4	!
10	5347·47	*t*oN	<13·2	3	!j
11	5348·50	*m*oN	<11·2	3	:j
12	5349·35	*t*oN	<13·2	3	!
14	5351·32	*p*4	<12·0	3	:

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1928					
Apr.					
15	5352·35	*t*4N	<13·4	4	!
16	5353·34	*s*oN	<13·0	3	!
17	5354·46	*q*oN	<12·5	3	:
20	5357·37	2*s*N	<12·9	3	:
22	5359·41	*q*1N	<12·5	3	:
23	5360·45	*q*oN	<12·5	3	!
24	5361·37	*q*oN	<12·5	4	(!
26	5363·34	*q*2N	<12·5	4	!t
27	5364·41	*p*oN	<11·8	2	:it
28	5365·44	*p*4N	<12·0	3	(!
29	5366·37	*p*4N	<12·0	4	(!
30	5367·39	2*p*N	<11·7	4	(:
May					
5	5372·42	2*m*N, *l*4N	<11·1	3	(i
6	5373·44	*n*oN	<11·5	3	(:i
7	5374·39	*r*2N, 2*q*N	<12·4	3	:
8	5375·36	*p*oN	<11·8	2	;
9	5376·37	*r*4N, *q*oN	<12·5	3	!
10	5377·40	*r*oN	<12·3	4	:
11	5378·38	2*s*N	<12·9	3	!
12	5379·38	*s*oN	<13·0	3	:
15	5382·40	*r*oN, *q*oN	<12·4	3	:j
16	5383·41	*p*oN	<11·8	3	i
17	5384·37	*r*4N, *q*2N	<12·5	3	!
19	5386·41	*r*oN, (*q* glimpsed)	<12·3	3	:
22	5389·37	*p*4N	<12·0	3	(!
26	5393·41	*p*4N	<12·0	3	(:
June					
4	5402·39	*o*4N, *n*2N	<11·5	2	;.
5	5403·37	*k*4N, *l*2N	<11·1	3	.t
July					
13	5441·57	*k*oN	<10·8	2	:t
14	5442·55	*g*6, =*k*	10·95	3	!t
17	5445·60	*q*oN	<12·5	4	:§
Aug.					
13	5472·61	*x*oN	<14·6	3	!¶
14	5473·56	*m*oN	<11·2	3	:j¶
15	5474	*x*2N	<14·7	3	:§
18	5477·63	*x*oN	<14·6	3	!§
20	5479·63	*n*oN	<11·5	3	!
23	5482·61	*x*4, 6*y*	<14·63	2	:§
25	5484·59	*x*9, =*y*	<14·91	3	:i§
27	5486·60	*x*10, 2*y*, 8*z*	<14·85	3	!j§
29	5488·62	(*x*12), =*y*	<14·93	2	!§
31	5490·63	*x*oN	<14·6	3	(:§
Sept.					
1	5491·56	*x*oN	<14·6	4	(!§
2	5492·67	*w*oN	<13·9	3	(i§
4	5494·51	*l*2N, *m*oN	<11·2	3	(!
6	5496·53	*p*oN	<11·8	3	!
7	5497·61	=*y*	<14·83	3	!§
8	5498·52	*n*oN	<11·5	3	!
9	5499	*x*9, 6*y*	<14·76	3	!j§
10	5500·55	*m*oN	<11·2	3	;
11	5501·57	*g*4, *k*2	10·95	3	!*
1928					
Sept.					
12	5502·57	=*g*, 1*k*	10·77	3	!¶
13	5503·60	*g*5, *k*2	11·00	3	:¶
14	5504·45	*k*6, =*m*	11·16	2	:
15	5505·52	=*p*	11·77	2	;¶
16	5506·55	*r*4, 2*q*	12·43	3	i§
17	5507·53	*t*1, 8*w*	13·40	4	!§
18	5508·48	*w*1	14·04	1	i§
19	5509·50	*w*4, 1*x*	14·43	4	:j§
20	5510·56	=*x*	14·54	4	:§
22	5512·57	*w*9, 3*x*	14·40	3	!§
25	5515·55	*w*7, 8*x*	14·22	4	!§
Oct.					
14	5534·55	*t*oN	<13·2	3	:
16	5536·51	*u*oN, 2*w*N	<13·8	4	!
17	5537·54	*w*oN	<14·0	3	!
18	5538·61	*t*4N	<13·4	3	!
19	5539·52	*t*oN	<13·2	3	!
21	5541·47	*t*oN	<13·2	3	!
24	5544·58	*t*oN	<13·2	3	!
25	5545·56	*q*2N	<12·6	3	(:
28	5548·53	*n*oN	<11·5	3	(!
30	5550·58	*r*oN	<12·3	3	(!
31	5551·54	*n*oN	<11·6	3	(:
Nov.					
3	5554·51	*r*oN	<12·3	4	(!
4	5555·46	*t*oN	<13·2	3	!
9	5560·52	*t*oN	<13·2	4	!
10	5561·52	(*g*11, *k*10), *m*4, 2*n*	11·37	3	!
11	5562·40	*g*3, 3*k*	10·80	4	!
12	5563·55	*g*4, =*k*	10·90	4	!
13	5564·53	*g*7, 1*k*	10·94	4	!
14	5565·65	=*g*, *k*2	10·85	3	!
15	5566·52	*g*6, 2*k*	10·90	4	!
16	5567·52	*g*4, =*k*	10·90	4	!
17	5568·69	*g*5, *k*5	11·05	3	!
18	5569·46	*g*8, *k*6, =*m*, 6*n*	11·16	3	!
19	5570·46	*n*4, =*p*, 8*r*	11·78	4	!
20	5571·57	=*r*, =*q*	12·38	3	!
Dec.					
15	5596·32	*q*4N	<12·6	3	!
16	5597·28	*q*oN	<12·5	3	:
17	5598·62	2*p*N	<11·7	2	!
18	5599·58	*t*4N	<13·4	3	!
19	5600·57	*t*4N	<13·4	3	!
20	5601·54	*t*oN	<13·2	3	:
22	5603·29	*r*oN	<12·3	3	(!
23	5604·57	*r*oN	<12·3	3	(!
27	5608·26	*p*oN	<11·8	3	(:
28	5609·55	*r*2, 4*q*	12·33	2	(!
29	5610·31	*r*4, 1*q*	12·50	3	(!
1929					
Jan.					
2	5614·28	*r*oN	<12·3	3	!
4	5616·57	=*r*	12·30	2	:
5	5617·29	=*r*, (*p*4, *q*2)	12·40	3	!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1929 Jan.					
6	5618·39	*q*7, (3*s*)	12·84	3	!
6	5618·61	*q*6, (4*s*)	12·79	2	!
7	5619·58	*t*3	13·35	2	!
Feb.					
4	5647·54	*to*N	<13·2	3	!
5	5648·52	*to*N	<13·2	3	!
9	5652·52	=*s*	13·02	2	!j
11	5654·33	*q*oN	<12·4	3	:
14	5657·53	*to*N	<13·2	3	!
25	5668·54	*k*4, =*m*	11·11	3	(!j
26	5669·51	*m*1, =*n*	11·38	3	(!
Mar.					
11	5682·46	*so*N	<13·0	3	:
12	5683·49	2*s*N	<12·9	3	:
14	5685·42	*to*N	<13·2	3	!
16	5687·51	*q*4N	<12·6	3	:
25	5696·33	*ro*N	<12·3	4	(!
Apr.					
1	5703·50	2*t*N	<13·1	3	:
4	5706·41	*to*N	<13·2	3	!
7	5709·35	*t*2N	<13·3	4	!
11	5713·35	*t*2N	<13·3	3	!
15	5717·32	*q*oN	<12·4	3	(!
18	5720·35	*p*oN	<11·8	3	(!
23	5725·38	*p*oN	<11·8	3	(!
24	5726·42	2*p*N	<11·7	3	(:
26	5728·41	3*g*, 3*k*	10·65	3	!
28	5730·45	=*g*, *k*2	10·85	3	!j
29	5731·41	*g*2, 2*k*	10·80	3	!
May					
3	5735·40	*k*6, =*m*, (2*o*)	11·20	3	!
4	5736·43	=*o*, 5*p*	11·52	2	:
5	5737·36	=*n*, =*o*, 6*p*	11·48	2	!j
6	5738·42	*r*3, 3*q*	12·37	3	:
7	5739·42	4*s*	12·82	2	:
July					
10	5803·62	*p*4N	<12·0	3	.t
12	5805·61	2*p*N	<11·7	3	.t
13	5806·62	*p*2N	<11·9	3	:
15	5808·62	*p*4N	<12·0	4	:
18	5811·62	2*r*N	<12·2	3	:
Aug.					
14	5838·57	*t*4, 2*u*°	13·54	4	:§
15	5839·64	*wo*N	<13·8	2	it¶
30	5854	*x*°6	14·84	1	:§
Sept.					
12	5867	*to*N	<13·2	...	?
20	5875·51	*so*N	<13·0	4	(!
21	5876·57	*to*N	<13·2	4	(!
24	5879·52	*s*4N	<13·2	4	(;§
Oct.					
1	5886·54	*uo*N	<13·8	3	!
3	5888·57	*t*4N	<13·4	3	!
6	5891·57	*wo*N	<13·9	4	!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1929 Oct.					
7	5892·56	*t*4N	<13·4	4	:
8	5893·55	*t*8N, (4*w*N)	<13·6	3	!
9	5894·58	*u*2N, *wo*N	<13·9	4	!
10	5895·56	*uo*N	<13·8	3	!
11	5896·54	*uo*N	<13·8	3	!
12	5897·65	*u*2N	<13·9	4	!
13	5898·62	2*u*°	13·68	2	!
13	5898·68	*t*°1	13·30	2	!
14	5899·54	(*p*′2), 3*r*	12·00	3	!
14	5899·62	*p*′1, 5*r*	11·94	3	!
15	5900·62	*m*′2, 2*n*	11·38	3	(!
15	5900·65	*m*′1, 2*n*, (*g*′12, *k*10)	11·32	3	!
16	5901·55	*g*′7, *k*3, *m*′1	11·11	3	(!
17	5902·57	*g*′9, *k*1, 1*m*′	11·08	4	(!
18	5903·54	*m*′2, 2*n*	11·33	2	(:
19	5904·55	*m*′4, =*n*	11·43	2	(!
26	5911·53	*uo*N	<13·8	4	!
31	5916·51	*to*N	<13·2	3	!j
Nov.					
4	5920·53	*t*6N, (*w* seen)	<13·5	4	!
7	5923·55	*uo*N	<13·8	3	!
14	5930·53	*so*N	<13·0	3	!
21	5937·37	*q*oN	<12·4	3	!i
22	5938·52	*q*oN	<12·4	2	
23	5939·56	*so*N	<13·0	3	!
24	5940·39	*to*N	<13·2	3	:
26	5942·52	*uo*N	<13·8	4	!
28	5944·32	*q*oN	<12·4	3	i
30	5946·53	*uo*N	<13·8	4	!
Dec.					
1	5947·49	*w*2N	<14·0	4	!
4	5950·52	*uo*N	<13·8	3	!
5	5951·47	*so*N	<13·0	3	!j
6	5952·26	*r*4N	<12·5	3	:
7	5953·52	*t*4N	<13·4	3	!
8	5954·53	*to*N	<13·2	3	!
9	5955·52	*p*2N	<12·0	3	(;
11	5957·53	*ro*N	<12·3	3	(:
12	5958·72	*so*N	<13·0	3	!
13	5959·50	*p*oN	<11·8	3	(:
18	5964·24	*ro*N	<12·3	3	:
19	5965·32	*q*2N	<12·5	3	:
20	5966·42	*to*N	<13·2	3	!
23	5969·23	*g*′6, 3*l*	10·96	3	:
24	5970·57	*g*′1, =*k*′	10·82	4	:
26	5972·24	*l*3, *m*′1	11·20	3	!
28	5974·26	*g*′7, *k*2	10·97	4	:
29	5975·42	*g*′2, *k*4, *l*2	11·00	3	!
30	5976·28	*g*′9, *k*5, =*l*, 11*n*	11·09	3	!
31	5977·29	*m*′2, 3*n*	11·30	3	!
1930 Jan.					
1	5978·39	*n*8, =*p*′, 5*r*	11·96	3	!
2	5979·31	=*r*, =*q*′	12·37	3	!
7	5984·57	*so*N	<13·0	3	:
25	6002·27	*q*oN	<12·4	3	!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1930					
Jan.					
26	6003·27	*q*2N	<12·5	3	!
28	6005·57	*s*oN	<13·0	3	!
29	6006·30	*s*4N	<13·2	3	!
30	6007·32	*s*oN	<13·0	3	!
31	6008·52	*s*oN	<13·0	[3]	!
Feb.					
1	6009·28	*q*2N	<12·5	3	!
2	6010·37	*t*oN	<13·2	4	!
3	6011·30	*q*2N	<12·5	4	!
3	6011·57	*t*oN	<13·0	3	:
4	6012·55	*t*oN	<13·0	3	!
5	6013·29	*r*2N	<12·4	3	(!
6	6014·57	*q*6N, 2*s*N	<12·9	4	:
7	6015·55	*r*oN	<12·3	3	(!
11	6019·29	*m*4N, 2oN	<12·4	3	(!
12	6020·29	*n*oN, *o*oN	<11·5	3	(:
13	6021·27	*p*oN	<11·8	3	!
15	6023·27	*q*6N, *q*oN	<12·5	3	:
16	6024·41	*s*oN	<13·0	3	!
18	6026·31	*q*4N	<12·6	3	!
19	6027·31	*q*oN	<12·4	3	:
19	6027·53	*s*2N, 2*t*N	<13·1	3	:
20	6028·53	*g*6, *k*′10	11·20	2	i
21	6029·33	*g*4, *k*′2	10·95	3	:i
21	6029·45	*g*4, *k*′6	11·05	2	
21	6029·53	*g*6, *k*′6, 2*m*, (5*n*′)	11·12	3	;
22	6030·32	(*m*2), =*n*′	11·40	2	:
22	6030·56	*m*2, =*n*′	11·38	3	;
23	6031·42	(*m*10), *n*′4, =*o*	11·61	3	;
24	6032·53	*r*′4, 4*q*	12·38	3	:
Mar.					
3	6039·57	2*t*N	<13·1	3	!
5	6041·52	*s*oN	<13·0	3	!
7	6043·54	*s*oN	<13·0	3	:
10	6046·53	*n*4N, *o*6N	<11·7	3	(!
17	6053·53	*p*4N	<12·0	4	(:
18	6054·45	*s*oN	<13·0	3	:
22	6058·31	*q*4N	<12·6	3	!
23	6059·52	2*s*N	<12·9	3	:j
24	6060·51	*q*oN	<12·4	3	:j
27	6063·38	*t*oN	<13·2	3	:
28	6064·32	*s*oN	<13·0	3	[!]
29	6065·43	*t*oN	<13·2	3	!
30	6066·34	*t*2N	<13·3	4	!
31	6067·51	*q*4N	<12·6	3	:j
Apr.					
1	6068·37	2*r*N	<12·2	3	;
3	6070·49	*s*oN	<13·0	3	:
4	6071·32	*p*2N	<11·9	3	:i
5	6071·32	*p*2N	<11·9	3	(!
6	6072·41	*p*4N	<12·0	3	(!
8	6074·43	*p*oN	<11·8	4	(!
9	6075·43	*n*oN	<11·5	2	(:
10	6076·35	*m*oN	<11·2	3	(i
11	6077·47	*n*oN	<11·5	3	(:
13	6079·44	*g*6, *k*′6	11·10	3	(:

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1930					
Apr.					
14	6080·32	*g*8, =*n*′	11·32	2	(i
15	6081·33	*m*6, *n*′4	11·58	2	!
16	6082·35	*r*′2, (8*q*)	12·30	3	!
17	6083·35	=*s*°	13·02	2	!
May					
1	6098·40	*q*oN	<12·4	4	:
8	6015·37	*n*4N, *o*oN	<11·5	3	(:
11	6018·36	*n*oN	<11·5	4	(!
15	6022·35	*k*10N	<11·3	2	i
17	6024·36	*r*oN	<12·3	4	:
July					
1	6159·61	*g*′2, =*k*	10·85	2	.j
4	6162·62	*g*′4, *k*2	10·95	3	.
5	6163·61	*g*′4, =*k*	10·90	3	.jt
7	6165·60	*g*′6, *k*4, 4*m*′	11·03	3	!
8	6166·62	(*g*6), *k*3, 2*m*′	11·02	2	:t
9	6167·62	*k*4N	<11·0	2	(t:
30	6188·58	*s*oN	<13·0	3	!
31	6189·60	*r*oN	<12·3	3	;
Aug.					
1	6190·56	*p*oN	<11·8	3	;
2	6191·59	*r*oN	<12·3	3	:i
3	6192·58	*s*oN	<13·0	3	:
5	6194·52	*t*oN	<13·2	3	!
8	6197·58	*n*oN	<11·5	3	(!
10	6199·61	*n*2N	<11·5	3	(!
11	6200·58	*m*4N, 2*o*N	<11·4	3	(:
14	6203·57	*n*oN	<11·5	3	(!
15	6204·56	2*p*N	<11·7	4	(!
16	6205·59	2*r*N	<12·2	3	(!
17	6206·63	*n*oN	<11·5	4	(:
21	6210·59	*s*oN	<13·0	3	:
22	6211·62	*s*4N	<13·2	3	!
23	6212·63	*s*oN	<13·0	3	!
24	6213·62	*s*oN	<13·0	3	!
25	6214·60	*s*oN	<13·0	3	!
26	6215·58	*r*4N, *q*oN	<12·5	3	;
27	6216·53	*r*oN	<12·3	3	:i
28	6217·64	2*s*N	<12·9	3	;
29	6218·55	*r*2N	<12·4	3	:
30	6219·61	2*r*N	<12·2	3	;
31	6220·58	*s*oN	<13·0	3	;
Sept.					
1	6221·57	*s*2N	<13·1	3	!
2	6222·62	*t*oN	<13·2	3	!
3	6223·64	*u*oN	<13·8	3	!
4	6224·53	*n*oN	<11·5	3	;
5	6225·67	*t*oN	<13·2	3	!
6	6226·62	*p*2N	<11·9	3	(!
7	6227·55	*m*oN	<11·2	3	(!
8	6228·52	*m*oN	<11·2	3	(!
10	6230·52	2*m*N, *l*4N	<11·1	3	(!
15	6235·49	*w*4N	<14·15	3	[!]§
21	6241·50	*o*′8, 2*p*°	11·80	3	:i¶
24	6244·53	*t*°9, 1*u*°	13·74	3	!§

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1930 Oct.					
3	6253·48	*m*oN	<11·2	3	(i
5	6255·52	*p*oN	<11·8	3	(;
6	6256·57	*p*oN	<11·8	4	(!
7	6257·53	*o*2N	<11·7	3	(!
8	6258·53	*p*oN	<11·8	3	(:
9	6259·60	2*p*N	<11·7	3	(!
13	6253·38	*r*oN	<12·3	4	:
14	6264·42	*r*oN	<12·3	3	:
15	6265·41	*r*oN	<12·3	3	:
16	6266·63	*t*oN	<13·2	3	!
17	6267·55	*n*2, 2*o*′	11·53	...	:
19	6269·63	$=n$, $=o'$	11·48	3	:i
20	6270·57	*n*6, $=p'$	11·77	3	!
21	6271·52	$=r$, $=q'$, (*r*′4, 2*q*)	11·40	3	!
22	6272·51	*t*′2	13·31	2	!
25	6295·58	$=u^{\circ}$	13·78	1	!
29	6279·55	*t*4N	<13·4	3	!
Nov.					
9	6290·30	*n*oN	<11·5	3	(:
11	6292·30	*l*oN	<11·0	3	i
12	6293·54	*q*oN	<12·5	3	(!
13	6294·40	*s*oN	<13·0	4	:
14	6295·52	*s*2N	<13·1	3	!
15	6296·56	*s*oN	<13·0	3	!
16	6297·56	*t*oN	<13·2	3	!
17	6298·52	*s*oN	<13·0	?	!
18	6299·64	*g*6, *k*′9, *l*′4	11·14	3	:
20	6301·33	$=p'$, 6*r*	11·89	3	:
20	6301·62	$=p$, *r*′2	12·09	3	!
22	6363·58	*t*oN	<13·2	4	!
Dec.					
12	6323·32	*n*12, *p*′4, 6*r*	12·00	3	[:]
12	6323·43	*r*4, 7*t*′	12·73	2	!
1931 Jan.					
1	6343·33	*n*oN	<11·5	3	(!
7	6349·54	*p*oN	<11·8	3	(!
8	6350·27	*q*oN	<12·5	3	!
9	6351·53	*r*oN, *q*oN	<12·4	3	(!
10	6352·27	*m*′4, 7*n*	11·25	3	!
10	6352·57	2*m*, $=n'$	11·28	3	!
11	6353·32	*g*′10, *k*4, 2*m*′, 10*n*	11·00	3	!j
12	6354·30	*m*′7, 9*n*	11·28	2	!
12	6354·57	*m*2, *n*′2	11·48	2	!
13	6355·55	*p*2, *r*′2	12·14	3	!
14	6356·30	2*q*	12·30	3	!
15	6357·40	$=t$	13·21	1	!
15	6357·62	*t*7	13·56	3	!
24	6366·59	*s*oN	<13·0	3	:
26	6368·55	*s*oN	<13·0	3	!
27	6369·59	*s*oN	<13·0	3	!
Feb.					
5	6378·30	2*s*N	<12·9	2	:
6	6379·30	*q*4N	<12·6	3	:
7	6380·29	2*s*N	<12·9	3	:

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1931 Feb.					
8	6381·50	*q*oN	<12·5	2	i
9	6382·55	*s*2N	<13·1	4	!
10	6383·29	*s*oN	<13·0	3	!
11	6384·29	*q*4N	<12·6	3	!
11	6384·49	*t*oN	<13·2	3	!
12	6385·28	*q*oN	<12·5	3	!i
13	6386·44	*q*4N	<12·6	3	:
14	6387·29	2*s*N	<12·9	3	!
15	6388·34	*s*oN	<13·0	3	!
17	6390·42	$l'3$, $=m$	11·18	3	:i
17	6390·60	*l*′4, 2*m*	11·15	3	:
18	6391·54	$=g$, (*k*′8), *l*′2, 4*m*	11·02	3	:
19	6392·54	*g*9, (*k*′12), $=m$, *n*′2	11·36	3	;
20	6393·58	*p*2, 2*r*′	12·04	2	:j
21	6394·30	*p*2, (6*r*)	11·94	3	!
22	6395·30	$q^{\circ}9$, $3s^{\circ}$	12·88	2	!
Mar.					
7	6408·45	*s*oN	<13·0	3	:
14	6415·45	*t*oN	<13·2	3	!
16	6417·46	*s*oN	<13·0	3	:
18	6419·54	*p*oN	<11·8	3	i
20	6421·46	*t*oN	<13·2	3	!
21	6422·43	*t*oN	<13·2	3	!
22	6423·38	*t*oN	<13·2	3	!
25	6426·52	*s*2N	<13·1	3	:
26	6427·38	*q*oN	<12·5	3	(!
29	6430·40	*p*2N	<11·9	3	(:
31	6432·32	*p*4N	<12·0	3	(:
Apr.					
3	6435·32	*s*oN	<13·0	3	!
4	6436·35	*t*oN	<12·0	4	!
5	6437·33	*t*oN	<13·0	3	!
6	6438·37	*s*oN (*t* seen)	<13·2	3	:
7	6439·52	*n*oN	<13·2	3	:
8	6440·46	*q*4N	<13·0	3	:
9	6441·52	*n*oN	<11·5	3	:
10	6442·45	*s*oN	<12·6	4	!
12	6444·33	*s*oN	<11·5	3	;
13	6445·45	*r*oN	<13·0	3	!
15	6447·35	*t*oN	<13·0	3	!
16	6448·52	*m*oN	<12·3	3	;
18	6450·47	*s*oN	<13·2	3	!
19	6451·37	*s*oN	<13·0	3	!
20	6452·43	(*p*3), *r*′3	12·19	3	:
21	6453·45	$=n$, 6*r*	11·73	2	;
22	6454·45	*g*6, *k*′8	11·15	3	:
23	6455·35	*g*1, *k*′3	10·89	4	(!
25	6457·45	*g*5, *k*′6	11·10	2	(;
26	6458·43	*g*5, (*k*′8)	11·13	2	(i
27	6459·43	*g*4, *k*′8	11·05	3	(:
28	6460·43	*g*6, *k*′8, ($=m$)	11·16	2	(
May					
1	6463·36	*p*oN	<11·8	4	(!
3	6465·35	*s*oN	<13·0	4	!
21	6483·37	*m*2N	<11·3	3	(i
24	6486·37	*n*6N, (2*p*N)	<11·7	2	:t

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1931					
May					
28	6490·37	*m*2	11·30	1	(i
30	6492·40	*l*oN	<11·0	3	(i
31	6493·38	*m*oN	<11·2	3	(.
June					
7	6500·39	*r*4N, (*q*)	<12·3	4	.
July					
7	6530·60	*p*oN	<11·8	4	(.j
9	6532·61	*n*oN	<11·5	2	(i
10	6533·62	*n*4N, (*p*)	<11·6	4	:
11	6534·62	*r*2N, *q*oN	<11·5	4	:
12	6535·60	*r*2N, 2*q*N	<11·4	4	:
13	6536·61	*q*2N	<11·6	4	:
15	6538·57	*p*oN	<11·8	3	:
16	6539·57	*r*oN	<12·3	3	!
17	6540·62	*q*oN	<12·5	3	!
18	6541·62	*s*oN	<13·0	3	!
19	6542·58	*r*2N, *q*oN	<12·4	4	:
20	6543·58	*r*oN	<12·4	3	:
21	6544·61	*q*oN	<12·5	3	!
22	6545·60	*r*oN	<12·3	3	;
23	6546·57	*q*2N	<12·5	4	!
24	6547·60	*q*2N	<12·5	4	:
25	6548·63	*s*oN	<12·5	4	!
26	6549·62	*s*oN	<13·0	3	!
27	6550·63	*r*oN	<12·3	3	!
28	6551·61	*n*oN	<11·5	4	(!
29	6552·62	*m*oN	<11·2	4	(!
Aug.					
1	6555·62	*r*oN	<12·3	3	(!
3	6557·62	*g*6, 4*m*′	11·04	2	(;
4	6558·61	*k*6, *m*′4	11·26	3	(!j
5	6559·63	*m*′4, 2*n*	11·38	2	(;
6	6560·60	*p*°4, 4*r*°	12·13	3	(!
7	6561·62	*q*4	12·56	2	(!j
29	6583·66	*r*oN	<12·3	4	(!
31	6585·67	*r*4N, *q*oN	<12·5	4	(!
Sept.					
7	6592·54	*g*°6, *k*°5, *m*′1, 7*n*	11·11	4	;§
8	6593·54	(*g*8, *k*′9), *m*4, 4*n*	11·29	3	;¶
12	6597·58	*t*′8, 6*w*	13·62	3	!¶
20	6605·53	= *y*	14·83	2	!§
Oct.					
5	6620·48	*q*4N, 2*s*N	<12·8	3	:
7	6622·50	*m*′4, 2*n*	11·38	4	!
8	6623·55	(*g*′9, *k*4), *m*′2, 2*n*	11·25	4	:i
9	6624·65	*g*′9, *k*5, *m*′3, 4*n*	11·26	3	!
10	6625·65	*n*6, 2*p*′	11·72	2	!i
12	6627·48	*t*°2	13·21	2	!
12	6627·61	*l*′2, 4*u*°	13·45	1	!
13	6628·60	*w*6, (glimpsed)	14·24	1	!
31	6646·32	*r*oN	<12·3	3	:
Nov.					
1	6647·40	*t*oN	<13·2	3	!
2	6648·47	*q*oN	<12·5	3	(:
3	6649·44	*s*oN	<13·0	3	!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1931					
Nov.					
6	6652·55	*u*oN	<13·8	4	!
8	6654·65	*u*oN	<13·8	3	!
10	6656·28	*q*oN	<12·5	4	:
11	6657·44	*t*oN	<13·2	3	!
13	6659·45	*t*oN	<13·2	3	!
13	6659·65	*u*oN	<13·8	3	!
14	6660·43	*t*4N	<13·4	3	!
15	6661·52	*u*oN	<13·8	3	!
16	6662·52	*t*4N	<13·4	4	!
17	6663·53	*t*4N	<13·4	3	:
18	6664·58	*t*oN	<13·2	3	:
21	6667·52	*q*oN	<12·5	3	(!
22	6668·52	*q*2N	<12·5	4	(!
25	6671·46	*m*oN	<11·2	4	(!
27	6673·41	*n*oN	<11·5	3	(:
28	6674·28	*q*oN	<12·5	3	:
29	6675·34	*t*oN	<13·2	4	:j
30	6676·28	*p*′4, 4*r*	12·04	3	:j
30	6676·50	*m*′4, 2*n*	11·38	2	(!
30	6676·67	(*k*′10), 6*m*	11·14	1	i
Dec.					
1	6677·42	*g*′4, 6*k*	10·78	2	:i
2	6678·42	*g*′7, 2*k*, 1*l*, 1*m*′	11·00	3	:
3	6679·51	*g*′7, *k*2, =*l*, =*m*′	11·07	3	!
4	6680·28	*g*′7, 4*k*, 2*l*, 1*m*′	10·96	4	:j
5	6681·29	*g*′7, 4*k*, 4*l*, =*m*′	10·95	3	:
6	6682·47	= *m*′, 4*l*	11·00	2	:i
8	6684·30	*m*′2, =*l*	11·15	3	:j
8	6684·70	= *m*, *l*′2	11·15	3	:j
9	6685·27	*m*′6, 2*n*	11·43	3	!j
9	6685·52	*n*′2, 2*o*	11·49	2	!j
10	6686·44	*p*′3, 7*r*	11·91	3	:j
11	6687·34	*r*1, =*q*′	12·38	3	:j
12	6688·65	*s*oN	<13·0	4	:
1932					
Jan.					
1	6708·37	*w*oN	<19·9	3	!
2	6709·27	*s*oN	<13·0	...	!j
4	6711·41	*t*oN	<13·2	...	!
5	6712·55	*n*′6, 4*p*	11·67	2	!
6	6713·46	= *l*, 2*m*′	11·05	2	;
6	6713·53	*o*′6, 2*p*	11·90	1	;i
8	6715·35	*p*′4, 9*r*	11·95	2	!
9	6716·28	*q*′2, =*r*	12·46	3	!
11	6718·60	*s*oN	<13·0	3	;
30	6737·30	*q*oN	<12·5	4	!
31	6738·27	*q*oN	<12·5	3	:
Feb.					
1	6739·28	*s*oN	<13·0	3	!
2	6740·30	*t*oN	<13·2	3	!
3	6741·30	*s*oN	<13·0	3	!
7	6745·30	*t*4N	<13·4	3	!
8	6746·30	*s*oN	<13·0	3	!
9	6747·50	*s*1N, *t*1N	<13·1	3	!
10	6748·30	*q*4N	<12·6	3	!
14	6752·37	*k*′6, 4*m*	10·91	2	(!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1932 Feb.					
14	6752·57	*l′*6, 3*m*	11·20	3	!j
15	6753·55	*l′*9, 4*m*, (*g*6, *k′*5)	11·22	3	(!
16	6754·56	*m*oN	<11·2	2	(!
19	6757·29	*o*oN	<11·5	2	(!
22	6760·30	*r*oN, *q*oN	<12·4	3	!
Mar.					
6	6773·53	*t*oN	<13·2	3	!
8	6775·50	*t*oN	<13·2	3	!
11	6778·47	*q*oN	<12·5	3	;
12	6779·31	*q*oN	<12·5	3	(;
13	6780·44	*q*4N	<12·7	3	(!
14	6781·31	*q*oN, *r*4N	<12·5	4	!
18	6705·50	*g*6N, *k*4N	<11·1	2	(!
20	6787·33	*p*4N, 2*r*N	<12·1	4	(!
21	6788·32	*p*oN	<11·8	4	(!
22	6789·32	*p*4N	<12·0	3	(!
23	6790·32	*t*oN	<13·2	3	!
24	6791·33	*t*oN	<13·2	3	!
26	6793·35	*u*oN	<13·8	4	!
28	6795·43	*u*oN	<13·8	3	!
29	6795·42	*u*oN	<13·8	3	!
30	6797·42	*t*oN	<13·2	3	!
Apr.					
1	6799·32	*t*oN	<13·2	3	!
3	6801·45	*q*oN	<12·5	4	!i
4	6802·43	1*t*N	<13·1	3	:
5	6803·42	*t*oN	<13·2	3	!
6	6804·42	*s*1N	<13·1	4	:
7	6805·37	*t*oN	<13·2	3	:
8	6806·43	*t*oN	<13·2	4	!
9	6807·43	*t*oN	<13·2	3	!
10	6808·37	*q*oN	<12·5	4	!
10	6808·46	*s*oN	<13·0	3	:
11	6809·47	*q*4N	<12·6	4	(!
12	6810·43	*r*oN, *q*oN	<12·4	3	(!
14	6812·35	*p*6N, *r*oN	<12·2	4	(!
16	6814·42	*o*oN	<11·5	3	(i
17	6815·33	*r*oN	<12·3	4	(!
18	6816·43	*n*2N	<11·5	3	(:
19	6817·32	*n*oN	<11·5	3	(!
20	6818·43	*l*oN	<11·0	3	(;
24	6822·43	*r*oN	<12·3	3	(:
29	6827·35	*s*oN	<13·0	4	!
May					
1	6829·40	*s*oN	<13·0	3	:
2	6830·35	*s*oN	<13·0	4	!
7	6835·40	*q*oN	<12·5	3	:
8	6836·37	*s*oN	<13·0	3	!
9	6837·43	*n*oN	<11·5	2	:
10	6838·43	*m*oN	<11·2	3	:
11	6839·42	*m*2N	<11·3	4	!
15	6843·37	*l′*2, 6*m*, (*g*2, *k′*4)	10·97	3	(:
16	6844·42	*g*4, *k′*4	11·00	2	(.
17	6845·42	*g*6, *k′*4	11·05	3	(.
19	6847·37	*g*4, *k′*2	10·95	4	(:
22	6850·37	*m*2, *n′*2	11·43	3	:
26	6854·39	*p*4N, 1*r*N	<12·0	3	.

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1932 July					
2	6891·60	*p*oN	<11·8	4	.
3	6892·61	1*r*N	<12·2	3	.
7	6896·60	*r*2N, *q*oN	<12·4	3	.
8	6897·60	*r*oN	<12·3	3	;j
9	6898·59	*n*2N, (*p*)	<11·5	3	;
10	6899·61	*p*oN	<11·8	3	.
11	6900·60	*l*oN	<11·0	2	i
13	6902·61	*q*2N	<12·5	3	:
14	6903·58	*r*oN	<12·3	3	;
15	6904·62	*r*oN	<12·4	3	!
17	6906·62	*m*oN	<11·2	3	(!
20	6909·62	*n*oN	<11·5	4	(!
21	6910·62	*r*oN	<12·3	3	(!
22	6911·62	*p*6N, 2*r*N	<12·2	3	(:
23	6912·59	*r*2N	<12·4	3	(:
24	6913·62	*p*4N	<12·0	4	(;
25	6914·59	*p*oN	<11·8	3	(;
26	6915·61	*r*2N	<12·4	4	(:
27	6916·61	*r*oN	<12·3	4	(:
28	6917·62	*q*oN, *s*oN	<13·0	4	!
29	6918·59	*q*2N, *s*oN	<10·3	3	!
30	6919·63	*q*2N	<12·5	4	:
31	6920·60	*s*2N, 1*t*N	<13·1	3	!
Aug.					
2	6922·57	*s*oN	<13·0	4	!
3	6923·62	*t*oN	<13·2	3	!
4	6924·60	*t*oN	<13·2	3	!
5	6925·57	*t*2N	<13·3	4	!
6	6926·62	*t*oN	<13·2	4	!
7	6927·60	*t*2N	<13·3	3	!
8	6928·55	*r′*6, 6*q*	12·41	3	:j
8	6928·65	*p′*4, 8*r*	11·97	3	!
9	6929·53	*g′*6, 6*k*	10·80	4	;
9	6929·61	*g′*4, 6*k*, 6*l*, 4*m′*	10·80	4	!
10	6930·62	(*g′*6, 4*k*), =*m′*, 3*l*	11·02	4	!
11	6931·53	*g′*8, *k*2, *l*2, (=*m′*)	11·10	1	i
12	6932·58	*m′*6, *n*2	11·43	4	:
13	6933·65	*p′*6, 4*r*	12·12	3	!
17	6937·66	*r*oN	<12·3	3	(!
Sept.					
1	6952·65	*u*oN	<13·8	4	!
3	6954·63	*t*4N	<13·4	4	!
4	6955·45	*q*oN	<12·5	4	:i
5	6956·66	*w*oN	<13·9	3	!
6	6957·60	*t*oN	<13·2	3	!
7	6958·52	*q*2N	<12·5	3	i
7	6958·67	*t*oN	<13·2	4	!
10	6961·56	*t*oN	<13·2	4	!
11	6962·65	*t*4N	<13·4	3	!
12	6963·56	*r*oN	<12·3	4	(:
12	6963·64	*t*oN	<13·2	4	:
13	6964·58	*m*oN	<11·2	3	(:
14	6965·62	1*r*N	<12·2	4	(!
15	6966·60	*p*oN	<11·8	4	(:
15	6966·66	*q*oN	<12·5	4	(!
16	6967·58	*r*oN	<12·3	4	(!
17	6968·56	*r*4N, (*q*)	<12·5	3	(!

	J.D. 242 . . .	Comparisons	Mag.	W.	Sk.
1932 Sept.					
18	6969·54	*m*oN	<11·2	2	(;
19	6970·69	*r*oN	<12·3	3	(:
20	6971·50	*r*oN	<12·3	3	(:
21	6972·50	*q*oN	<12·5	4	!
22	6973·62	*r*oN	<12·3	4	i
24	6975·50	*t*oN	<13·2	4	!
25	6976·52	*m*oN	<11·2	3	i
25	6976·58	*t*oN	<13·2	3	!i
29	6980·49	*g*′6, 2*k*	10·90	3	!
30	6981·52	(*g*′8, 2*k*), =*l*, 2*m*′	11·01	4	!
Oct.					
1	6982·54	*l*3, =*m*′, 2*o*′, 3*n*	11·27	3	:
2	6983·39	=*n*, *o*′6	11·63	3	;.
2	6983·65	*n*1, *p*′1	11·69	4	!
3	6984·65	=*q*′, 2*r*	12·36	2	!
4	6985·55	*q*5, =*s*	12·85	3	!
5	6986·55	*u*′2, (8*w*)	13·74	2	!
7	6988·60	*w*2N	<14·0	1	!
20	7001·36	*s*oN	<13·0	3	;
21	7002·52	*r*4N	<12·5	4	(!
23	7004·47	*s*oN	<13·0	3	:
24	7005·51	*t*4N	<13·4	4	!
25	7006·46	*q*oN	<12·5	3	:
26	7007·47	*t*4N, (*u*)	<13·4	4	!
28	7009·50	*w*oN	<13·9	3	!
29	7010·49	*w*2N	<14·0	3	!
30	7011·38	*t*oN	<13·2	3	:
30	7011·55	*w*4N	<14·1	4	!
31	7012·49	*w*oN	<13·9	4	!
1932 Nov.					
1	7013·47	*w*4N	<14·1	4	!
2	7014·55	*w*oN	<13·9	4	!
3	7015·49	*o*oN	13·8	3	!
4	7016·52	*w*2N	<14·0	4	!
5	7017·57	*u*oN	<13·8	4	!
6	7018·40	*q*oN	<12·5	3	(:
6	7018·62	*t*oN	<13·2	3	(:
7	7019·47	*r*oN	<12·3	3	(:
7	7019·58	*t*oN	<12·2	3	:
9	7021·48	*r*oN	<12·3	3	(:
10	7022·55	*r*oN	<12·3	3	(!
11	7023·53	*r*oN	<12·3	4	(!
12	7024·52	*r*oN	<12·3	3	(!
16	7028·43	=*l*, =*m*′	11·10	2	(:
17	7029·30	*k*7, 2*o*′	11·26	3	;
18	7030·31	=*k*, =*o*′	11·16	2	:
19	7031·27	*o*′6, =*n*	11·63	2	;.
20	7032·30	*p*′2, 4*r*	11·99	3	:
21	7033·47	*q*4, =*t*′	12·93	3	!j
Dec.					
5	7047·60	2*t*N	<13·1	3	:
10	7052·26	*n*oN	<11·5	3	(:
11	7053·60	*n*4N	<11·6	3	(!i
15	7057·66	*p*oN	<11·8	3	(:
17	7059·26	*n*3, 2*p*′	11·65	3	:
18	7060·26	2*k*, (*m*′2)	11·01	3	;
18	7060·39	1*k*, =*m*′	10·98	4	:
19	7061·60	=*m*, 2*n*′	11·28	3	(:
21	7063·30	*p*′4, 4*r*	12·07	3	!
22	7064·26	*q*2	12·56	2	!
23	7065·55	*t*6	13·51	1	!

The observations reveal 33 outbursts or "maxima," two of which should certainly be classed as secondaries. A few other maxima may have taken place, especially in the month of June, when the variable is almost unobservable.

The maximum of 1928 February was of the "anomalous" type, the slow rise being well observed from $13^{m}.0$ to $10^{m}.7$ (see *Ast. Nach.*, 5580). The rise to the maximum of 1929 October was somewhat slow, and the long maximum of 1931 April appears to have been more than usually round-topped. Secondary maxima were observed for the first time at the end of 1928 and beginning of 1929. The maximum of 1930 December followed the previous one after an unusually short interval. In the majority of cases the variable remained above twelfth magnitude for 10 days at the long maxima and 4 days at the short.

Zaragoza, Spain:
1933 *December.*

MICROMETRICAL MEASURES OF DOUBLE STARS.

(25TH SERIES.)

W. Milburn

The micrometrical measures are given as in previous lists, all being made with the 24-inch (Calver) reflector.

Name	B.D.	1900 R.A.	1900 Decl.	P.A.	Dist.	Mags.	Nights	Date 1933 +	
	°	h m	° ′	°	″				
Es 1601	+39·9	0 3·4	+39 28	97·1	5·71	...	3	·964	
Es 1607	+39·320	1 18·6	40 12	210·4	3·29	...	2	·905	
M 6	...	30·9	39 36	55·1	6·20	...	2	·951	
M 7	+38·324	36·0	39 4	314·3	3·88	...	3	·955	
Es 158	+40·378	43·3	40 28	49·7	7·45	...	2	·987	
M 9	+40·388	46·4	40 55	316·2	5·87	...	2	·987	
Es 162	+36·369	51·8	36 17	209·4	11·49	...	2	·965	
Es 163	+36·375	52·1	36 17	21·1	5·18	...	2	·965	
M 10	...	57·4	38 50	50·2	3·58	...	2	·905	
Es 1955	+37·558	2 22·2	38 3	27·3	7·97	...	2	·916	AB
				334·8	8·95	...	3	·933	AC
				279·4	7·37	...	1	·966	BC
M 14	...	3 0·4	39 29	12·2	4·81	...	2	·917	
M 18	...	4 13·1	40 14	157·1	3·23	...	2	·965	
Es 239	+35·856	16·5	35 59	239·3	5·85	...	2	·965	
Es 1717	+40·1132	54·0	40 20	224·4	1·85	...	2	·965	
Es 62	+40·1277	5 17·2	41 2	59·9	2·81	...	2	·965	AB
				304·6	12·45	...	2	·965	AC
Es 2100	+37·1739	7 26·5	37 47	193·9	2·53	9·3 10·3	3	·211	
Es 2101	+37·1771	40·5	37 25	8·2	5·01	9·5 9·6	2	·185	AB
				47·7	15·45	C = 12·5	2	·219	BC
Es 1638	+39·2285	9 47·4	39 7	70·5	2·79	9·5 10·2	2	·230	
M 66	+36·2116	10 40·0	36 29	184·6	4·43	9·5 9·8	2	·230	
Es 1737	+36·2121	41·1	36 10	280·7	1·89	...	2	·237	
Es 1653	+40·3375	18 23·7	40 27	184·4	7·79	...	2	·702	
Es 2021	+38·3294	43·2	38 46	303·8	2·91	...	2	·702	BC
				251·1	...	...	1	·706	AB
Es 1669	+40·3845	19 38·0	40 44	154·6	2·17	...	2	·765	
Sch 742	...	53·4	39 6	140·6	7·81	9·3 9·5	2	·634	
Es 2051	+39·4134	20 15·6	39 19	310·3	4·41	...	2	·765	
Es 2050*	+38·4020	16·5	39 2	96·1	5·96	...	2	·809	AB
				189·9	10·97	...	2	·809	AC
M 21*	...	20·8	39 43	347·8	4·76	...	2	·634	
Es 261*	+39·4695	21 48·2	39 57	166·3	5·00	...	2	·780	
Es 1586	+40·4721	22 1·5	41 5	41·8	4·18	9·5 9·6	2	·873	
Es 1587	...	14·7	40 37	299·7	3·79	...	2	·953	
Es 1588	+40·4781	15·1	40 40	97·2	5·83	...	2	·951	
Es 266	+39·4958	48·8	39 48	83·8	12·95	8·5 10·5	1	·972	
Es 2078	+35·4962	23 3·9	35 48	304·6	6·29	...	3	·966	
Es 1703	+40·5007	6·0	41 4	116·0	3·97	...	2	·951	
M 505*	+39·5054	13·2	39 33	142·3	9·08	...	3	·870	

Name	B.D.	1900 R.A.	1900 Decl.	P.A.	Dist.	Mags.	Nights	Date 1933 +
	°	h m	° ′	°	″			
Es 2002*	+37·4833	23 19·4	37 20	101·7	3·95	...	2	·986
Es 267	...	25·8	38 57	183·2	2·55	...	3	·870
Es 1599	+40·5125	34·5	40 20	347·1	3·33	...	2	·965
M 34	+39·5164	42·8	39 28	323·7	8·20	...	2	·986

Notes on stars marked *

Es 2050. C = 12·7 mag. ; added by Milburn.
M 21. Correct place given.
Es 261. Mags. 9·2, 9·3 ; n. is the brighter.
M 505. Correct place given.
Es 2002. Correct B.D. number given.

New Double Stars

Milburn No.	B.D.	1900 R.A.	1900 Decl.	P.A.	Dist.	Mags.	Nights	Date 1933 +	
	°	h m	° ′	°	″				
807	...	0 20·6	+39 42	334·5	3·39	10·0 10·3	2	·498	
808	...	23·6	39 25	289·5	8·33	10·0 10·1	2	·815	
809	...	24·0	39 4	322·9	4·52	11·0 11·2	3	·654	
810	...	39·3	39 7	2·9	5·79	9·8 9·9	2	·823	
811*	...	56·8	39 26	15·7	5·91	10·0 10·1	2	·823	
812	...	1 19·6	39 6	57·3	4·71	11·0 11·2	2	·040	
813	...	34·6	39 53	178·1	3·41	11·7 12·2	2	·053	
814	+39·444	52·1	39 23	321·3	7·15	8·8 12·2	3	·046	
815	...	2 3·6	39 5	192·6	2·91	10·7 11·0	3	·553	
816	...	4·1	39 5	270·4	6·02	11·0 11·5	2	·521	
	+38·501	26·2	38 38	353·0	11·76	9·5 11·2	2	·070	AB
				315·0	19 ±	C = 9·8	2	·070	AC
817	...	58·9	39 11	226·1	4·31	9·7 11·2	2	·120	
818	...	3 0·4	38 55	328·4	5·10	10·0 11·2	2	·120	
819*	...	13·5	38 23	157·0	4·58	9·8 10·0	2	·098	
820	...	18·8	40 0	66·2	2·18	12·0 14·0	3	·690	
821	...	19·3	40 4	316·1	6·45	9·8 10·5	2	·131	
822*	...	28·0	39 48	167·9	5·41	10·0 10·8	2	·063	
823	...	5 5·4	38 32	143·8	6·91	10·0 11·0	2	·119	
824	...	39·6	36 57	12·4	7·93	10·0 11·0	1	·194	
825	...	40·0	36 56	97·4	5·26	9·9 11·0	2	·148	
826*	...	40·0	36 58	339·2	5·95	9·8 9·9	2	·182	
827	...	40·3	39 15	76·1	4·08	11·0 12·0	1	·194	
828	...	42·3	39 25	254·1	3·97	10·0 11·0	2	·192	
829	...	51·8	38 35	217·6	4·49	10·0 11·5	2	·146	
830	...	6 41·2	37 12	359·5	5·02	10·1 11·8	4	·152	
831	...	7 14·5	39 22	351·0	4·71	10·3 11·5	3	·194	
832	...	28·6	39 0	108·8	4·52	10·7 11·7	3	·170	
833	...	48·5	38 13	312·0	6·29	11·0 11·3	2	·234	
834*	...	48·7	38 34	291·9	7·83	9·9 10·2	1	·233	
835	...	48·7	38 11	1·3	5·33	11·5 12·0	1	·238	
836	...	48·9	38 8	83·5	5·12	11·0 11·0	1	·235	
837	...	8 7·3	38 41	80·8	5·53	11·0 12·0	2	·157	
838*	...	27·1	34 8	18·5	3·77	10·0 10·2	3	·232	
839*	...	27·2	34 6	279·6	10·20	9·5 10·0	2	·234	

Milburn No.	B.D.	1900 R.A.	1900 Decl.	P.A.	Dist.	Mags.		Nights	Date 1933 +	
	°	h m	° ′	°	″					
840	...	8 43·7	37 34	133·9	6·31	10·0	10·5	3	·193	
841	...	9 36·9	38 18	173·9	6·93	10·0	10·3	2	·226	
842	...	46·1	39 58	280·2	5·31	10·5	11·2	2	·219	
843*	...	56·5	32 40	52·1	2·92	9·5	11·0	1	·298	
844*	+31·2129	10 16·2	31 38	197·5	2·29	9·5	11·0	2	·239	
845*	...	40·1	32 41	358·1	3·04	10·5	11·0	2	·287	
846*	...	45·3	32 15	257·9	5·91	11·0	11·2	3	·232	
847	+32·2080	46·5	32 30	85·7	5·43	9·0	10·0	2	·226	
848	+32·2093	52·7	32 40	212·7	8·41	9·5	10·5	2	·237	
849*	...	11 15·7	32 7	216·7	2·50	11·0	11·0	3	·233	
850	...	17 11·1	38 40	188·4	5·06	10·5	10·7	2	·626	
851	+39·3307	59·9	39 26	37·3	6·04	9·5	10·2	3	·619	
852	...	18 12·6	38 38	42·0	8·14	9·3	10·0	2	·626	
853*	...	15·6	39 16	136·4	6·06	10·0	10·0	2	·626	
854	...	23·9	38 43	16·8	4·43	10·0	10·2	2	·664	
855	...	52·9	39 1	232·0	4·43	10·0	11·2	3	·619	
856	...	53·5	38 46	93·5	2·62	10·5	11·5	3	·619	
857	...	53·9	39 17	340·6	4·06	9·8	10·0	2	·654	
858*	...	54·7	38 9	113·3	5·13	10·5	11·5	3	·659	
859	...	56·6	39 8	238·0	3·66	10·5	11·5	3	·673	
860	...	19 14·8	38 10	187·1	5·12	9·5	10·0	2	·647	
861	...	17·6	39 20	114·1	5·64	9·5	10·0	2	·664	
862	+38·3558	19·0	38 12	59·2	9·77	8·6	10·6	3	·664	
863*	...	19·1	38 13	278·6	6·63	9·4	10·5	2	·647	
864	...	20·8	39 27	287·9	3·77	9·6	11·2	2	·709	
865	...	21·9	39 6	10·3	5·49	10·0	10·5	2	·731	
866*	...	22·6	38 59	279·9	4·56	9·5	11·0	2	·686	
867	...	24·4	38 59	238·8	5·66	10·0	11·0	3	·690	
868	...	25·6	39 18	167·4	3·70	10·2	10·6	2	·780	
869	...	26·6	39 6	21·9	5·45	10·0	11·2	2	·780	
870	...	30·4	39 3	252·0	6·04	10·5	10·6	2	·638	
871	...	30·4	39 2	199·0	7·33	9·3	10·5	3	·642	
872	...	30·4	39 4	273·8	8·72	9·5	9·5	2	·638	
873	...	30·4	39 1	51·0	5·95	9·7	13·0	3	·642	
874	...	34·1	39 9	15·0	2·83	12·0	13·0	1	·788	AB
				205·8	8·5 ±	C = 13·5		1	·788	AC
875	...	37·8	40 44	188·8	5·43	10·0	10·1	2	·776	
876*	...	45·8	38 42	44·0	4·56	10·0	10·5	3	·632	
877	...	52·3	39 2	34·5	4·61	11·5	12·5	3	·677	
878	...	52·4	38 59	193·2	3·16	10·5	12·6	3	·669	
879	...	52·4	39 2	141·6	3·97	10·5	11·1	3	·677	
880	...	53·2	39 4	273·5	3·62	9·8	11·0	2	·634	
881	+38·4001	20 14·9	38 57	116·7	8·39	9·3	11·0	2	·765	
882*	...	16·4	39 2	286·9	5·02	10·0	11·5	3	·800	
883	+39·4241	30·6	39 29	304·9	9·79	9·5	10·5	2	·702	
884	...	35·8	39 41	202·0	4·68	10·0	10·2	2	·734	
885	...	36·5	39 32	52·5	1·80	10·0	11·0	7	·801	
886	...	51·3	39 18	141·0	6·84	10·0	11·0	2	·697	
887	...	51·7	39 17	301·9	4·62	10·0	11·0	2	·686	
888	...	21 3·2	38 28	57·6	3·89	11·6	13·2	2	·702	
889	...	3·4	38 33	0·8	5·83	10·2	11·5	2	·702	
890	...	3·5	38 29	249·2	5·00	10·8	11·7	2	·697	

Milburn No.	B.D.	1900 R.A.	1900 Decl.	P.A.	Dist.	Mags.	Nights	Date 1933 +	
	°	h m	° ′	°	″				
891	...	21 7·1	38 54	250·9	8·48	9·5 10·0	3	·693	
892	...	7·2	38 53	189·7	3·93	9·9 11·2	2	·668	
893	...	8·7	38 50	149·5	3·43	10·0 11·0	3	·851	
894	...	11·5	38 47	203·0	2·75	10·0 10·2	2	·873	
895	...	14·2	39 4	181·5	5·45	9·5 12·0	2	·653	
896*	...	26·8	39 47	168·2	3·25	10·7 10·9	3	·747	
897	...	27·3	39 46	27·2	4·33	10·5 10·5	2	·776	
898*	...	27·6	39 39	253·2	5·76	9·7 10·2	2	·734	
899*	...	29·1	39 11	40·8	3·47	10·3 10·7	4	·840	
900	...	29·3	39 13	282·0	6·62	10·5 11·5	2	·873	
901*	...	31·1	39 33	235·5	5·65	10·2 10·4	3	·694	
902	...	41·4	39 17	314·8	5·18	10·0 10·1	3	·694	
903	...	22 3·9	39 25	201·9	4·24	10·0 10·5	3	·783	
904	...	19·6	38 24	105·1	5·27	10·0 11·0	2	·686	
905	...	25·5	38 41	235·6	5·75	10·0 10·1	3	·806	
906	...	34·8	39 29	223·9	4·43	10·0 10·5	3	·727	
907	...	23 2·3	39 29	217·9	5·10	10·0 11·0	2	·780	
908	...	2·8	39 22	333·8	4·93	10·0 12·5	3	·727	
909	...	8·8	38 21	335·8	5·91	10·0 10·1	2	·743	
910	...	13·4	39 32	99·8	7·44	9·3 11·0	3	·931	AB
				344·5	13 ±	C = 12·0	2	·951	AC
911	...	34·1	38 59	321·0	6·60	10·0 10·1	2	·780	AB
				247·2	16 ±	C = 11·5	2	·780	AC
912	...	52·2	39 37	30·7	3·43	11·5 11·8	3	·900	

*Notes on stars marked **

811. f. B.D. +39°·239 (mag. 8·7).
819. At 211°·0; 80″ ± from B.D. +38°·694 (mag. 9·2).
822. AC; 41°·2; 35″ ±; C = 10·3 mag.; 1933·046.
826. BC; 291°·8; 24″ ±; 1 n.; 1933·1944.
834. At 359°·6; 54″; from B.D. +38°·1837 (mag. 9·5).
838. At 264°·5; 123″ ± from B.D. +34°·1858 (mag. 9·3).
839. At 214°·0; 135° ± from B.D. +34°·1858 (mag. 9·3).
843. s.p. B.D. +32°·1971 (mag. 9·5).
844. AC; 261°·7; 17″ ±; 1 n.; 1933·2382.
845. At 86°·5; 135″ ± from B.D. +32°·2072 (mag. 8·5).
846. At 279°·7; 108″ ± from B.D. +32°·2078 (mag. 9·5).
849. At 300°·5; 70″ ± from B.D. +32°·2138 (mag. 9·5).
853. n. of B.D. +39°·3380 (mag. 7·5).
858. 80″ ± n. of B.D. +38°·3373 (mag. 6·2).
863. n.f. B.D. +38°·3558 (mag. 8·6). =M. 862.
866. AC; 89°·5; 15″ ±; C = 10·0 mag.; 2 n.; 1933·686.
876. p. B.D. +38°·3771 (mag. 9·3).
882. At 243°·8; 70″ ± from B.D. +38°·4020 = Es 2050.
896. AC; 74°·6; 19″ ±; C = 10·6 mag.; 1933·775.
898. f. B.D. +39°·4579 (mag. 7·1).
899. Double planetary nebula.
901. $1^{m}\cdot2$ p. M. 28.

Erratum

P. 60. R.A. of Star No. 10, *for* $4^{h}\ 47^{m}\ 37^{s}$ *read* $4^{h}\ 41^{m}\ 37^{s}$.